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REPORT OF THE WORKSHOP

ON

UNIFORMITY OF INFORMATION REPORTING

ON

BIOMETHANATION SYSTEMS

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Workshop Co-sponsors:
UN Economic and Social Commission
for Asia and the Pacific (ESCAP)
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Equity Policy Center (EPOC)

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The Equity Policy Center (EPOC) is a non-profit research, communications, and educational group, founded in 1978 to promote a more equitable distribution of opportunities and resources both in the United States and in other countries. EPOC's primary goal is to identify the need for, and to promote, policies and programs aimed at ameliorating the position of the world's most vulnerable populations, focusing particularly on the women among them. To set this goal in the wider context of social change and economic development, EPOC emphasizes a sectoral approach to issues such as household and rural energy, or food production and consumption, where the differential impact of policies and programs on women and men is critical.

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Report of the Workshop on Uniformity of Information Reporting on Biomethanation Systems

INTRODUCTION

This workshop had its origin in the growing concern among specialists in the development and application of renewable-energy technologies about the difficulty they were having in benefitting from the experience of others and applying reported results to their own situations. This difficulty has been particularly serious in the field of biomethanation (biogas production).

Although biomethanation systems have been in use for many years in many parts of the world, the lack of a systematic way of reporting the results of experimentation with, and use of, such systems has made comparisons among them, and their relative evaluation, extremely difficult. This problem arises from the lack of agreement on parameters and variables to be measured, the conditions of measurement, and even the units of measurement.

Compounding this confusion is the fact that there exists no basis for cost comparisons because different direct costs are usually reported, and many important indirect costs, such as taxes and subsidies, are frequently not taken into account. The situation has reached a point where there are even disagreements over whether or not a given system "works." Thus, the task of the policy maker in establishing programmatic budget priorities in energy systems has been made particularly difficult.

In the interests of advancing the useful application of biomethanation techniques, the Equity Policy Center (EPOC), on behalf of the United States Agency for International Development (USAID), conducted a survey among experts in the field. There was a uniformly positive response from those surveyed that a meeting was needed to address this issue and, with a grant from USAID, EPOC undertook to organize the workshop whose results are reported here. Co-sponsoring the workshop with EPOC were the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) and the Commonwealth Science Council (CSC). With the assistance of the Government of Japan, ESCAP provided meeting and secretariat facilities in Bangkok and financial support for two participants from Asia; the CSC supported the attendance of a participant from Africa. Under a grant from USAID, EPOC supported the attendance of eight participants, including five from the United States, one from South America, one from Asia, and one from Europe. EPOC further arranged for participation by an expert from Egypt and another from Switzerland. In addition, attending at ESCAP's invitation, were experts from Burma and Thailand, and representatives of the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

Members of the workshop panel included scientists and engineers who are doing research on the fundamentals of biomethanation, working with large-scale systems and with small-scale systems in the field, and those in positions either to give technical advice to decision makers or with responsibility for making policy decisions at a national level. The panel also included social scientists experienced with the use of biomethanation systems in developing countries and with the general problems of social acceptability of such systems. Assisting the panel were representatives of international organizations concerned with these issues.

The workshop was organized to try to establish some order in reporting results of experimentation with and field use of biomethanation systems, by seeking agreement not only on a systematic method of reporting technical results, but also on a uniform approach to dealing with the socio-economic issues that, in the end, determine the acceptance and use of these systems.

RESULTS

After an initial period of general discussion of the issues, the workshop participants were divided into three working groups, each dealing with a different set of problems. In this way, the detailed discussions were focused on: Process Design and Construction; Operating Conditions, Analytical Measurements, and Monitoring; and Utilization, Health, and Environmental issues. A final plenary session dealt with overlapping issues and recommendations for further action.

The workshop succeeded in achieving its objective, which was to reach agreement on a set of categories of information to be used by the scientific and technical community to report the results of work on biomethanation systems. This has resulted in agreement on the parameters and variables to be measured, the units in which the measurements should be expressed, and the conditions under which measurements should be made. The panel hopes this agreement will facilitate the technical comparison of systems among countries and regions. The ultimate purpose is to make easier the task of the decision maker who must allocate part of a national budget to energy systems, by providing a coherent national data base to the technical advisors who are called upon for information and guidance.

SUMMARY OF DISCUSSION

This report deals with the two overall issues that face technical specialists and decision makers concerned with biomethanation systems. These are, first, biomethanation as an engineering process and second, the e and acceptance of biomethanation systems. The first involves technical data on the feedstock, digester, and the products, with a view to obtaining for each system the information needed for an adequate description of the design of the system, the properties of the input and output streams, the operating conditions, the performance of the system, and the uses of the products. Consideration of the second begins with the recognition that the purpose of dealing with biomethanation systems--or with any renewable-energy technology--is to meet certain individual and community needs in a way that will result in the acceptance and use of the system with the minimum economic cost/benefit ratio and the maximum social and ecological benefit.

Since biomethanation systems are of little interest unless they are widely accepted and used, the importance of the frequently intangible and generally unquantifiable social and ecological impacts, in conjunction with a conventional analysis of economic impacts, cannot be too strongly emphasized. Indeed, one of the more important results of the workshop discussions has been the recognition by a predominantly scientific and technical group that the socio-economic issues, including those many intangible impacts on a society or ecology that are not quantifiable and thus are usually ignored in conventional cost/benefit analyses, are generally more important than technical issues in governing the acceptance and use of biomethanation systems.

The discussions further made clear the concern of the participants about the need for a realistic recognition of the role of subsidies--those on products or systems being displaced by biomethanation as well as those that would encourage the use of biomethanation in favor of other approaches with less overall social benefit. In addition, the participants stressed the importance of the management of technical assistance and extension work to help the ultimate users, and the need to avoid the top-down approach, but involving the participation of the fabricators and users in the design of field systems.

The report stresses the importance of the minimum data that are necessary to describe the design and the process used in a biomethanation system, and other useful data that would characterize both the feedstocks and the uses of either the products or the system as a whole. It was not the intention of this workshop to be concerned with urban sewage-sludge digesters that are integrated with underground water-borne sewage systems, for which recognized standard technical approaches have long been established. Rather, the panel was concerned with pilot-plant and full-scale systems, with a strong emphasis on small-scale single-family, community, institutional, and industrial biomethanation installations.

In addition, the panel noted the importance of national governments' including statistics on biomethanation systems in the reports of statistical data that result from various national surveys and censuses.

The participants recognized that there are three groups of people who work with these systems:

- o scholars doing research on the fundamentals of biomethanation or supervising experimental work in the laboratory or field;
- o technicians implementing designs with local materials; and
- o those with little or no formal education who use these systems.

This report is not meant as a prescription for solving the technical problems facing these groups. It is, rather, the suggestion of a coherent approach that should be tested in all three situations and perhaps modified to produce a uniformly accepted method of reporting information that will make the tasks of all three groups easier, and provide a data base for use in evaluation and improvement of biomethanation systems. This is turn will make easier the task of the fourth group that consists of planners who, while not working with these systems in the same sense, are seeking informatio : the comparative performance of a variety of systems as a basis for regional and national planning.

RECOMMENDATIONS

1. Process Design and Construction

People dealing with biomethanation technology are urged to characterize the systems used by reporting a detailed description of the design and the design parameters and of any ancillary equipment used with the system, including a schematic illustration showing the details of the system. This description should also include the type, geometry, dimensions, and materials of construction of the digester and gas holder, and the specifications of ancillary equipment. It is equally important that the cost of constructing the digester (and gas holder) be reported in detail. This should include the cost and specifications of the materials and the cost of labor, with the latter disaggregated to the number of work-hours required and the cost per work-hour for each of the different skills required. Details of these recommendations are given in this report.

It is only by having this information that specialists in any and all regions and countries will be able to benefit from the results and experience of others in planning their own designs.

2. Operating Conditions, Analytical Measurements, and Monitoring

The panel recommends that measurements of a minimum number of parameters and variables associated with operation of a biomethanation plant be reported in a uniform way, using international units, so that results of a biomethanation project, whatever the scale and wherever performed, can be understood and used by people in other locations. These parameters and variables are described in detail in this report. To facilitate the gathering of data and the monitoring of the operation of the system, operators in the field should be provided with centrally managed mobile laboratories to monitor these minimum necessary measurements.

In addition to these measurements, measurement of other parameters and variables is recommended as useful, or even necessary in some cases, for analyzing the feedstock and for characterizing the end uses of the biomethanation system and its products (such as use of gas for energy and the residue for fertilizer, treatment of wastes, or improving public health and sanitation), or for assessing or monitoring digester performance. The panel recommends a uniform way of expressing measurement results in terms of concentrations, rates, and yields. The panel further notes precautions to be taken while sampling or performing analyses to insure the integrity of the results.

The panel also recommends methods for collecting data in the field where little or no instrumentation or laboratory facilities are available, and suggests the development of other methods, where necessary.

3. Use of the Products, Public Health and Sanitation, and Socio-Economic Issues

Biomethanation systems are accepted and used only to the extent that their products meet a need and that both the systems and their products meet certain socio-economic criteria. The panel recommends a list of parameters and variables whose measurements are needed to enable comparisons to be made among similar uses for the products (gas and liquid/solid effluent) and the systems. Recommendations are also made in this report for the system of units in which those measurements should be reported.

The panel stresses, however, the overriding importance of the socio-economic issues in arriving at realistic choices of biomethanation systems that will be accepted and used by the people for whom they are intended. The panel notes that these choices and initial decisions are generally made on the basis of technical criteria alone, with information that heretofore has usually been insufficient or inadequate as a basis for comparison. Even with the improved data base that would be established by adoption of the technical recommendations of this workshop, the panel observes that more significant in the decision-making process should be the consideration not only of an economic analysis based on actual expenditures and tangible benefits, but also of the many intangible social and ecological costs and benefits that cannot be quantified in conventional analyses. The panel recommends that such an analysis should be based on a checklist at least as inclusive as the suggestions made in the report.

4. National Statistics

A major part of the difficulty in evaluating the actual or potential usefulness of biomethanation to a national economy is the lack of statistical information on current use of this technology. Governments generally collect and report information only on systems installed under government programmes. The panel therefore recommends that national governments include information on all biomethanation systems in statistics gathered on a national basis. This information should include the number built, the number in use, the aggregate energy produced, the aggregate fertilizer produced, the uses of the energy, the increased crop production attributable to the use of the fertilizer, the construction costs, the cost of extension activities (including training of artisans), and any direct subsidies involved.

5. Follow-up Task Force

The panel recommends that a Task Force be formed by ESCAP and EPOC to follow up the recommendations of this workshop. The primary concern should be the identification of institutions and field projects with which to cooperate in testing the approach recommended by this workshop. These tests should be designed to span at least a year of operation, and the results should be presented to a follow-up meeting of this group.

6. Circulation for Professional Comment

Practical considerations have limited participation in this workshop to a relatively small number of individuals. Therefore, the panel recommends that this report be circulated for comment to a representative group of recognized experts and professional organizations for review and comment.

7. Accessibility of the Report

The panel urges that its report be translated into Spanish, French, and other appropriate languages to enable widespread dissemination and use, particularly in the developing countries.

I. PROCESS DESIGN AND CONSTRUCTION

The essential information that is required for the design and construction of a biomethanation system must also be reported in descriptions of the results of design and/or use of the system, to permit rational comparisons and evaluations to be made. This information can be grouped in the following five categories.

A. Classification of Biomethanation Systems

The different types of digesters and systems have traditionally been classified in several ways.[1] The following scheme would minimize misinterpretations.

1. Scale

   a. Family size

   b. Community size

   c. Large (agricultural, institutional industrial) size

Reports on scale must include the total digester volume in m^3 and the active volume as a fraction of the total volume.

2. Type of System*

   a. Batch

   b. Semi-continuous (single stage)

      i. With recycle (of digested slurry)

      ii. Without recycle (of digested slurry) or accumulation of solids

   c. Continuous (single stage)

      i. With recycle (of digested slurry)

      ii. Without recycle (of digested slurry) or accumulation of solids

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* Multi-stage systems are not considered in this report since they are primarily characteristic of urban systems.

B. Design of Biomethanation Systems

Detailed designs and specifications for various types of digester are available in several publications [1,2,3,4], but use of the following scheme is recommended.

1. Type of Digester*

a. Fixed Geometry - The dimensions and shape of the digester do not change with gas production.

i. Gas stored inside ("water pressure," e.g., Chinese type - approximately seven million of these are reported to be in use in China).

ii. Gas stored outside in separate gas holder.

b. Floating cover - The gas produced is trapped under the floating cover (bell) of the digester. This type is used extensively throughout the world and is often known as the KVIC** or Indian design.

c. Flexible Bag - The gas is stored inside the reactor as in the fixed-geometry type, but in this case the reactor is a flexible,cylindrical-shaped, plastic (or rubber) bag. (An alternative is to store the gas in a separate bag, making possible the potentially easier construction of two small bags in place of one large bag.)

d. Plug-Flow - This is a horizontal digester in which the ratio length/diameter >>1, giving an internal flow pattern approaching ideal flow.

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* There are many more types of digesters than are listed in this section (e.g., anaerobic filters, anaerobic baffled reactors, anaerobic contact digesters, up-flow sludge digesters, blanket reactors, two-stage reactors). This discussion is confined to those few types encountered in the field, primarily in developing countries.

** Khadi and Village Industries Commission (Bombay, India).

e. Dry Batch Fermentation - Substrate and inoculum are fed to a reactor vessel, which is then sealed, allowing fermentation to proceed for up to six months. (This type is well adapted to use of solid agricultural residues.)

The fixed-geometry, floating-cover, and flexible-bag types of reactors are most suitable for use with substrates commonly found in rural areas of developing countries.

2. Digester Specifications -

a. Materials of Construction (all quantities in metric units)

i. Type - brick, stone, concrete, steel, and any other materials used in the construction of the digester

ii. Amount - number, weight (kg), volume (m^3), area (m^2)

iii. Description - size (cm) of brick or stone, thickness (mm) of steel or plastic, special characteristics, pretreatment of materials

b. Finish of Inner and Outer Surfaces - all quantities in metric units

i. Type - cement (or other) plaster, asphalt coating, paint, etc.

ii. Amount - volume, weight used (m^3, kg)

iii. Description - thickness applied, (mm) special characteristics

c. Geometry/Dimensions (metric units)

i. Sphere

ii. Cylinder - axis horizontal (i.e., tunnel) or vertical

iii. Rectangular parallelepiped

iv. Other

d. Principal Features - Description or drawings should be provided

i. Inlet

ii. Outlet

iii. Mixing facilities

iv. Sampling ports and devices

v. Other

e. Installation

i. Above ground

(a) Insulation

(i) Type - straw, leaves, air, fiber, expanded foam, etc.

(ii) Thermal conductivity ($J \cdot {}^{o}C^{-1} \cdot cm^{-1} \cdot s^{-1}$)

(iii) Thickness (cm)

(iv) Permanent or replaceable

ii. Below ground

(a) Portion covered/not covered (m^2,%)

(b) Insulation

(i) Type - straw leaves, air, fiber, expanded foam, etc.

(ii) Thermal conductivity ($J. {}^{o}C^{-1}. cm^{-1}. s^{-1}$)

(iii) Thickness (cm)

(iv) Permanent or replaceable

(c) Mean temperature of earth (${}^{o}C$)

f. Heating - External or Internal

i. Source - solar, waste-heat recycle, biogas, other fuel

ii. Heat load ($J \cdot s^{-1}$, J/J gas produced)

g. Mixing

i. Mechanical

(a) Type of mixer

(b) Power input requirement (kW)

ii. Gas

(a) Pump - type, power input requirement (kW)

(b) Recirculation rate ($m^3 . h^{-1}$)

iii. Manual

iv. Sludge recycle

(a) Pump - type, capacity, power requirement (kW)

(b) Recirculation rate ($m^3 . h^{-1}$)

h. Process Control and Measurements

i. Safety devices

(a) Pressure-relief valve - number, type

(b) Flame arrester - number, type

(c) Water trap - number, type

ii. Temperature measurement/control - type

iii. Flow control - type

iv. Level control - type

v. Sampling ports and devices - type, location

3. <u>Gas Storage</u>

a. Gas holder

i. Integral with digester - volume (m^3)

ii. Separate - type, volume (m^3)

b. Materials of construction (see 2.a.)

c. Finish of inner and outer surfaces (see 2.b.)

d. Geometry/dimensions (see 2.c.)

e. Gas pressure (cm water head)

4. <u>Handling and Disposal of Effluent</u>

a. Storage facilities (if any)

b. Processing before disposal

i. Dewatering - type

ii. Drying - type

iii. Composting

iv. Enriching

v. Other

c. Method of disposal - pumping, gravity flow, hauling

i. Land disposal

ii. Other

C. <u>Design Process Parameters</u>

Successful performance of a biomethanation system depends on the values of a number of parameters and variables that control and describe the biomethanation process. Process temperature and the physical and chemical characteristics of the substrate are major factors that influence the rate of gas production. Process temperatures directly affect gas production by controlling the growth rate of the methanogenic bacteria, which are sensitive to sudden changes in temperature. Changes in substrate compositon or physical characteristics may also lead to fluctuations in gas production. In addition, other parameters (and variables) that strongly influence gas production include loading rate, flow rate, digester volume, and retention time.

Most of the parameters and variables listed in this section represent measurements that must be made to monitor operating conditions, and will thus be discussed in Part II <u>Operations and Conditions</u>. They are listed here briefly, however, because their design values determine the physical design of the digester.

The important measurements are listed below:

1. Temperature (^{o}C)
   a. Ambient
      i. Monthly average
      ii. Diurnal range
   b. Slurry
      i. Feed
      ii. Digester - specify location
2. Substrate
   a. Physical characterization
      i. Qualitative description - dung, poultry droppings, night soil, crop residues, other
      ii. Density ($kg \cdot m^{-3}$)
      iii. Particle size and distribution - range and average (mm)
      iv. Total volatile solids - weight %, ratio of weight/volume ($kg \cdot m^{-3}$)
      v. Total solids - weight %, ratio of weight/volume ($kg \cdot m^{-3}$)
   b. Chemical characterization (See II. OPERATING CONDITIONS)
   c. Pretreatment - mechanical, thermal, biochemical.
3. Loading Rate - Loading rate will depend on the type of digester, the nature of the feedstock, and the environmental conditions. (See II. OPERATING CONDITIONS for explanation of symbols.) ($kg_{VS} \cdot m^{-3} \cdot d^{-1}$; $kg_{TS} \cdot m^{-3} \cdot d^{-1}$; $kg_{COD} \cdot m^{-3} \cdot d^{-1}$)
4. Flow Rate - Rate at which feedstock (substrate plus water for mixing) flows through the system ($m^{3} \cdot d^{-1}$)
5. Digester Volume (m^3) (See A.1. above.)
6. Retention time (theoretical) (d)

7. Gas

a. Production rate - Clarifies the efficiency of the digester in producing gas, expressed in terms of volume of gas produced daily per unit volume of digester ($V_{gas}/V_{digester}$ per day, $m^3 \cdot m^{-3} \cdot d^{-1}$)

b. Yield - Clarifies the ability of the organic substrate to produce gas in the system, expressed in terms of volume of gas produced per unit weight of total solids or volatile solids fed to digester over a period of one retention time. (V_{gas}/w_{TS}, $m^3 \cdot kg^{-1}$; or V_{gas}/w_{VS}, $m^3 \cdot kg^{-1}$)

c. Composition - Expressed in terms of volume per cent ($m^3 \cdot m^{-3} \cdot 100$) of the chemical constituents of interest. For the digester design, only the methane (CH_4) content is of significant interest, but the content of hydrogen sulfide (H_2S) may need to be known (or estimated) for design or selection of some ancillary equipment. (See d. and e. below.)

d. Purification - Description of any chemical purification techniques needed to remove H_2S or carbon dioxide (CO_2) for proper operation of ancillary equipment.

e. Utilization - Burners, lamps, internal-combustion engines, refrigerators, heaters, etc. (thermal efficiency, $Q_{out} \cdot Q_{in}^{-1} \cdot 100$, or $P_{out} \cdot t \cdot Q_{in}^{-1}$ 100 where P_{out} is output power in kW, t is in hours, and Q_{in} is in kWh equivalent of heat input in joules)

8. Residue (See II. OPERATING CONDITIONS for details.)

a. Rate of production ($m^3 \cdot d^{-1}$)

b. Total solids content ($kg \cdot m^{-3}$)

c. Proximate analysis - N, P, K (weight %)

9. Utilization of residues - The residue that remains after the digestion of the organic substrate - i.e., the effluent plus any settled sludge that may be periodically removed from the digester - has many uses that depend on local conditions and needs. If the residue can be used as an animal feed supplement, for example, it may have a much higher value than if used as a fertilizer. The value of the parameters in 8 (above) can thus affect the economic feasibilty of the entire process, and therefore should be clearly given. (See III. UTILIZATION, HEALTH, AND ENVIRONMENTAL ISSUES.) Examples of various uses of the residue are:

a. Fertilizer and soil conditioner

b. Livestock or poultry feed

c. Other (e.g., growing algae, feeding fish)

D. System Design and Construction Costs

The dissimilarities in the designs of biomethanation systems make impractical any attempt to list all of the many items involved in design and construction, with costs assigned appropriately to each item. In order to make possible a comparison of design and construction costs in different countries, however, in the classification presented below various costs are grouped into categories that can be applied uniformly to any type of biomethanation system. The costs associated with the individual items under the various categories can then be added to obtain the capital cost of the system.

The four major categories, under which the individual cost items are to be grouped are:

- Digester
- Gas holder
- Ancillary equipment and accessories
- Process design and construction supervision

Examples of the individual cost items to be listed under each of these categories are shown in Table 1. It is important that all costs be reported in local currency with U.S. dollar equivalent, and that the year in which the cost was incurred be included.

With such information available for each system reported, reliable cost comparisons can be made.

Table 1. Capital Cost of Biomethanation System

Digester

Materials	Unit	Quantity	Cost per Unit	Total Cost
Item 1				
Item 2				
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			Subtotal	

Labor	Unit	Quantity	Workhours per Unit	Cost per Workhour	Total Cost
Excavation					
Building					
Plastering					
Backfilling					
Transportation of Materials					
Other Costs (Itemize)					
				Subtotal	

Gas Holder

Materials	Unit	Quantity	Cost per Unit	Total Cost
Item 1				
Item 2				
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			Subtotal	

Labor	Unit	Quantity	Workhours per Unit	Cost per Workhour	Total Cost
Fabrication					
Painting					
Transportation of Gas Holder					
Other Costs (Itemize)					
				Subtotal	

Auxiliary Equipment and Accessories

	Unit	Quantity	Cost per Unit	Total Cost
Equipment				
I-C engine				
Lamps				
Burners				
Other (Itemize)				
Accessories				
Pipe				
Valves				
Flame arrester				
Water trap				
Other (Itemize)				
			Subtotal	

Process Design and Supervision

Labor	
Fees	
Supplies	
Other (Itemize)	
Subtotal	
Total Capital Cost	

E. Preliminary Technical/Economic Evaluation

With the information on construction costs and the yields of gas and slurry, a financial analysis based on market prices can be carried out. This type of analysis is useful in determining the rates of return for a particular biogas plant, and can help in evaluating the various technical options available to satisfy specific end uses, e.g., cooking, lighting, and mechanical or electrical power. However, a financial analysis is fairly narrow in its scope since it uses market prices rather than "shadow" prices, which reflect the true economic worth to society of the inputs and outputs of the project. In addition, a financial analysis does not incorporate "secondary" benefits, e.g., improved public health, reduced reliance on imported fossil fuels, reduced deforestation. These benefits are difficult to quantify; nevertheless they are extremely important in assessing the technology. These latter factors are incorporated in a social analysis (social cost/benefit), and will be discussed at greater length in Section III. However, it is strongly recommended that this social analysis be used by governments to assess the viability of biomethanation systems, since it most accurately reflects the effect of the project on the fundamental objectives of the whole economy.

The actual construction cost of a digester is relatively easy to assess, although at some periods during the year the cost of unskilled labor may be virtually negligible since it is essentially idle. Determining plant life (depreciation) is difficult since there is still little information available, and assumptions vary between 15 and 40 years. However, depending on the discount rate, a life of more than about 25 years has little impact on benefit/cost ratios. Obviously, different parts of the plant will have different lifetimes, and these should be assessed accordingly.

Maintenance costs can also vary considerably depending on the design used. For example, a steel floating cover requires considerable attention and maintenance to prevent corrosion. In contrast, the water-pressure digester requires little maintenance. Also, while land costs can contribute significantly to overall costs, except in the most densely settled villages land can be treated as a zero-cost item since the quantities involved are so small. Finally, the labour involved in collecting the feed (e.g., manure, agricultural residues), mixing it with water, and feeding it to the digester has to be evaluated. In many cases this time is minimal, however, and often equivalent to the labour required to collect biomass for traditional uses, e.g., as a fuel or manure. Hence, this cost can often be neglected.

Evaluating the quantifiable benefits of a biogas plant is also fraught with many difficulties. The output of a plant consists of two streams, gas and slurry. Evaluation of the gas depends on three complex considerations: the quantity and composition of the gas; the mix of end uses; and the price, type, and burning efficiency of another fuel for which the gas may be substituted, e.g., kerosene, LPG, coal, or electricity. The first factor depends entirely on the feedstock and process-design parameters; however, the mix of the end uses determines what fuels may be used for calculating replacement costs. Finally, since the price and burning efficiency of displaceable fuels varies considerably, this factor can radically alter the value of biogas from the plant.

The benefits derived from the slurry depend on its use, e.g., as a fertilizer/soil conditioner, an animal feed, or as a feed for fish ponds. The value of the slurry in increasing crop yields depends on the fate of the nitrogen, and therefore on the handling procedures used.

In some cases this increase may be equivalent to spreading the biomass directly on the land without digestion, hence no benefits should be claimed. If the slurry is used as an animal-feed supplement, then the benefits from the slurry could be considerably greater than from the gas. Considerable care should be exercised in evaluating the benefits from the slurry, and these should be related to an original quantity of biomass. (See Section III. C.1.b. for a discussion of this issue.)

Table 2. A Preliminary Economic Appraisal of the Biomethanation System

Item	Amount
Investment Costs	
Digester Construction	
Gas Holder	
Ancillary Equipment and Accesories	
Process Design and Supervision	
Gas distribution system	
Other	
Total Investment	
Annual Operation and Maintenance Costs	
Dung, water, other feed materials	
Operating labor	
Repairs and maintenance	
Cost of capital (interest)	
Depreciation	
Civil construction (10-20 years)	
Ancillary equipment (including end-use devices) (10 years)	
Gas holder (10 years if steel)	
Others	
Other annual costs	
Total depreciation	
Total annual costs	
Annual Tangible Benefits (Income)	
Biogas (equivalent as kerosene, LPG, coal, electricity)	
Residue (*e.g.* as fertilizer, soil conditioner, feed supplement)	
Other	
Total annual income	

Profit = Annual income - Annual Costs

Return on invested capital = (Profit/Total Investment) x 100

II. OPERATING CONDITIONS, ANALYTICAL MEASUREMENTS, AND MONITORING

Successful operation of a biomethanation plant, whether an experimental research model, a family-size installation in the field, or a full-scale community or industrial plant, involves measurement and monitoring of the values of a large number of parameters and variables. In general, there are three categories of information: data needed for research and development purposes and for a full understanding of the process, minimum data necessary to describe a process so that conditions of operation are understood and can be repeated by others, and data that are needed to describe the products and uses of the system but are not crucial to day-to-day operation. There are some overlaps among these categories, of course, and the detailed R & D data are for the most part also subsumed under the second category. For the purposes of this report, therefore, in view of the emphasis on application and use of these systems, this dicussion will be confined to two major categories - minimum data needed to describe the biomethanation process, and the data needed to describe the products and uses of the system.

A. Minimum Data Needed to Describe the Biomethanantion Process

1. General operating conditions

   a. Starting procedure and inoculum

   b. Duration of run at reported conditions - days (d)

   c. Volumetric loading rate in weight of volatile solids per unit volume per day ($kg_{VS} \cdot m^{-3} \cdot d^{-1}$), and frequency of loading in days (d). (This is not applicable to batch systems.)

   d. Temperature of feed - mixed feed, water, solids (^{o}C)

   e. Mean retention time - hydraulic, solids (symbol θ, in days d)

   f. Recycling, if any, with details - active biomass, effluent

   g. Mixing method, frequency, and duration; relation to loading if semi-continuous

h. Mixing - power input if full-scale

i. Physical and chemical conditions inside system (digester and gas holder) - pH, temperature (^{o}C), pressure ($kg \cdot m^{-2}$)

j. Ambient temperature - air and/or soil (^{o}C)

2. Specific parameters and variables to be measured. - In Table 3 are listed the specific measurements that must be reported to provide an adequate description of the biomethanation process. They include analyses of both solid and slurry feedstocks, as well as digester contents. In some field operations it may not be possible or practical to make all these measurements because of the lack of adequate analytical equipment and instrumentation. When this is the case, it should be clearly noted.

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Table 3. Parameters to Be Measured, at A Minimum to Describe A Biomethanation System

Quantity to be Measured	Units	Where Measured: Feedstock – Solids and Slurries	Where Measured: Feedstock – Wastewater	Where Measured: Digester Effluent
Total Solids (TS) per unit weight or volume	$kg \cdot kg^{-1}$; $kg \cdot m^{-3}$	x	x	x
Total Suspended Solids (TSS) per unit volume	$kg \cdot m^{-3}$		x	x(c)
Volatile solids (VS),	$kg \cdot kg^{-1}$	x	x	x
Mineral matter (ash content) - per unit weight or volume	$kg \cdot m^{-3}$	x	x	x
Volatile suspended solids (VSS) per unit volume	$kg \cdot m^{-3}$		x(a)	x(c)
Chemical oxygen Demand (COD)(d) - at least for more dilute wastes	$kg \cdot m^{-3}$	x	x(a)	x(b)
Total kjeldahl nitrogen (TKN) per unit weight (%) or volume	$kg \cdot kg^{-1} \cdot 100$; $kg \cdot m^{-3}$	x	x	
Ammonium nitrogen (NH_4^+-N) - weight per unit volume	$kg \cdot m^{-3}$			x
Volatile fatty acids (VFA) (C_2+ C_3 to C_5) - weight per unit volume	$kg \cdot m^{-3}$			x
pH	-	x	x	x
Gas composition (% CH_4)	%			x
Gas production rate - gas volume per unit volume (digester) per day	$m^3 \cdot m^{-3} \cdot d^{-1}$			x
Particle size - range, distribution	mm	x		

Notes

a. Either one or the other (solids and slurries or wastewater)

b. In effluent if measured in influent

c. Only for digester treating wastewater

d. COD is the preferred way to express the concentration of a substrate because any change in COD between influent and effluent can be directly related to the methane produced (with the exception of accumulation or loss of biomass in the digester). In addition, volatile solids determinations are often unreliable. However, COD determination of slurries and solids is rendered delicate by the difficulty in obtaining a representative sample ... small amount. The material should be homogenized before sampling and great care should be used when sampling. At least three replications should be made before a result can be declared valid.

In the case of most operating biomethanation systems in the field, operators will not be able to gather much of the minimum data needed. In these situations, a centrally managed mobile laboratory unit, equipped to perform the necessary analyses, would provide these minimum data on the specific parameters and variables listed.

3. Parameters useful to describe biomethanation processes. - In addition to the minimum data needed, the values of other parameters are useful in describing all biomethanation processes because they may influence their performance. With the exception of scum formation, they all require more or less sophisticated laboratory equipment for their measurement. These include the following:

   a. Total alkalinity - expressed as $CaCO_3$ ($kg \cdot m^{-3}$)
   b. Acid-soluble phosphate ($PO_4^{\equiv}$, $kg \cdot m^{-3}$)
   c. Concentration of heavy metals and toxic compounds ($kg\ m^{-3}$)
   d. Thermal conductivity ($J \cdot {}^{o}C^{-1} \cdot cm^{-1} \cdot s^{-1}$)
   e. Microbial biomass, or microbial activity (F_{420}, other methods)
   f. Scum - thickness (m), material, hardness (ease of penetration or break up)
   g. Hydrogen content of gas ($m^3 \cdot m^{-3} \cdot 100$)

4. Data useful for characterizing feedstock, products, and end uses. - In Table 4 are listed the quantities whose measurements are useful and often necessary for adequate characterization of the feedstock of a biomethanation system and of its products, according to their various uses. Most of these measurements can be made only if a laboratory is available.

Table 4. Useful and Necessary Data for Characterization of Feedstocks, Products and Uses of Biomethanation Systems

Quantity to be Measured	Units	Uses of Products or System for which Indicated Measurements Should be Made (*indicates necessary data)						Where Measured	
		Health and Sanitation	Fuel/ Energy	Agriculture			Waste Treatment	Feedstock	Effluent
				Weed Control[a]	Fertilizer	Feed			
Volatile fatty acids	$kg \cdot m^{-3}$							X	
Total available carbon[b]	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$							X	
Cellulose, hemicellulose, lignin	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$		X		X	X		X	X
Starch	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$							X	
5-day Biological Oxygen Demand (BOD_5)	$mg_{O_2} \cdot l^{-1}$, $kg_{O_2} \cdot m^{-3}$						*		
Sulphates ($SO_4^{=}$)	$kg \cdot m^{-3}$							X	
Acid-soluble phosphate ($PO_4^{=}$)	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$							X	
Hydrogen Sulphide (H_2S)	% (weight)		X						X
Na, Ca, Mg	$kg \cdot m^{-3}$				X				
Total P, K, N	$kg \cdot m^{-3}$, $kg \cdot kg^{-1}$				*				X
Pathogenic, microorganisms, parasite eggs	number viable per 100ml	*			X	*	X		X
Seeds	number and % germination			*	X				X
Toxic heavy metals	$kg \cdot m^{-3}$, $kg \cdot kg^{-1}$	X			X	X		X	X
Protein content[c]	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$					X			X
Amino acids, nucleic acids	$kg \cdot kg^{-1}$, $kg \cdot m^{-3}$					X			X
Viscosity	$kg \cdot m^{-1} \cdot s^{-1}$				X				X
Specific heat (solids)	$J \cdot kg^{-1}$							X	
Thermal conductivity	$J \cdot {}^{o}C^{-1} \cdot m^{-1} \cdot s^{-1}$							X	
Biodegradable/Non-biodegradable material	% (weight), $kg \cdot kg^{-1} \cdot 100$		X		X	X	X		X

(a) Inactivation of weed seeds
(b) Carbon available to microorganisms as determined by batch digestion. (Details of methods should be stated)
(c) Determined by organic Kjeldahl nitrogen analysis (TKN minus NH_4^+ - N), or any other method, provided the method is described.

B. Expression of Results

Throughout this report, an attempt has been made to express measurement results in a consistent system of units. To achieve this consistency, the panel has adopted, with modifications deemed necessary and reasonable, the system suggested by the International Union of Pure and Applied Chemistry (IUPAC) and the International Association on Water Pollution Research (IAWPR), and used by the Commission of the European Communities.[5] In general, this has meant the expression of mass in terms of the kilogram (kg), length in terms of the meter (m) and time in terms of the seconds (s). Exceptions are recognized where it is more appropriate to use millimeters (mm), centimeters (cm), liters (1), grams (g), days (d), or hours (h). In addition, however, this means a uniform system of symbols and subscripts, to identify parameters, variables, and other quantities unambiguously and uniformly from system to system. A summary of special symbols, identifying subscripts, and example of use is given in this section, and a complete listing is given in Appendix B.

1. Concentrations - Concentration must be related to unit volume or unit weight. If the materials is wet, concentration should be referred to dry weight, or the moisture content should be reported. Recommended symbols are as follows:

Symbol	Name/Description	Units
S	Substrate	kg m^{-3}, or g l^{-1}
X	Active mass of microorganisms	kg m^{-3}, or g l^{-1}
o (subscript)	Refers to influent	
e (subscript)	Refers to effluent	
r (subscript)	Removed, disappeared, or transformed	

Examples:

S_o	Concentration of substrate (TS, VS, or COD) in the feedstock:	kg m^{-3}
X_e	Concentration of active mass of microorganisms (TS, VS, or COD) in the effluent:	kg m^{-3}

Expressing concentration of nitrogen compounds frequently causes some ambiguity. This concentration should be stated as the amount of nitrogen in the form intended to be measured, e.g., the form of ammonium ion (symbol: NH_4^+-N) per unit of weight of material analyzed (g (NH_4^+-N) kg^{-1}). If the nitrogen content of the substrate (manure, crop residues, etc.) is given, it must be referred to the dry weight of the substrate, or the moisture content (%) or Total Solids (TS) content (%) should be given.*

Phosphorus concentrations should be clearly identified as chemical P, $PO_4^{\equiv}$, Na_3PO_4, or P_2O_5.

* Nitrogen content is often reported in a variety of ways. These include ammonium nitrogen (NH_4^+ - N), organic nitrogen (org - N) total Kjeldahl nitrogen [TKN = (org - N) + (NH_4^+ - N)], nitrite nitrogen (NO_2^- - N), nitrate nitrogen (NO_3^- - N), and total nitrogen [Tot - N = TKN + (NO_2^- - N) + (NO_3^- - N)].

2. Rates - Rates (*i.e.*, time rate of change) should be expressed in terms of the unit working volume. Recommended rates and symbols are as follows:

Symbol	Name	Units
B_V (Note a)	Volumetric loading rate	$kg \cdot m^{-3} \cdot d^{-1}$
r_V (Note a)	Gas (specify methane content) or methane production rate per unit volume	$m^3 \cdot m^{-3} \cdot d^{-1}$, or $l \cdot l^{-1} \cdot d^{-1}$

The methane production rate is different from the gas production rate, and the distinction must be clear. When the gas production rate is given, the content (volume %) of methane - whose presence is indicated if the gas burns - should always be given, if possible.

Examples:

$B_{V(COD)}$	Volumetric loading rate of chemical oxygen demand [weight (kg) of COD per unit volume (m^3) per day (d)]:	$kg \cdot m^{-3} \cdot d^{-1}$
$B_{V(TS)}$	Volumetric loading rate of total solids [weight of total solids (kg) per unit volume (m^3) per day (d)]:	$kg \cdot m^{-3} \cdot d^{-1}$
$B_{V(VS)}$	Volumetric loading rate of volatile solids [weight of volatile solids (kg) per unit volume (m^3) per day (d)]:	$kg \cdot m^{-3} \cdot d^{-1}$
$r_{V(gas)}$	Gas production rate per unit volume [Volume of gas (m^3) per unit volume (m^3) per day (d)]:	$m^3 \cdot m^{-3} \cdot d^{-1}$ (65% CH_4, for example) (Note b)
$r_{V(CH_4)}$	Production rate of methane per unit volume (Volume of methane (m^3) per unit volume (m^3) per day (d):	$m^3 \cdot m^{-3} \cdot d^{-1}$

Notes: a. Subscript V refers to volume, whose symbol is V (See Appendix B, Symbols). It specifically means working (digester) volume here, however. Thus, loading rates and gas-production rates refer only to working volume.

b. Conditions of measurement must be specified, i.e., STP, temperature, pressure, wet (moisture content?) or dry gas.

3. Yields and Conversions - Yields and conversions should always be given as the ratio of output to input. The yield is the ratio of volume (m^3) of methane (CH_4) or biogas (i.e., total gas) produced to the weight (kg) of a given amount of material input [substrate (S_o), volatile solids (VS_o), total solids (TS_o), or chemical oxygen demand (COD_o)] added to the digester. Conversion of a given substance is the ratio of the weight (kg) of output to input. Both yield and conversion are represented by the symbol Y, with the distinction made clear by the appropriate subscripts. Both quantities are meaningful only if the retention time is specified.

Symbol	Name	Units
Y	Yield	$m^3 \cdot kg^{-1}$
	Conversion	$kg \cdot kg^{-1}$

Examples:

Y_{CH_4/S_o}	Yield of methane (m^3) per unit (kg) substrate (Note a, Note b)	$m^3 \cdot kg^{-1}$
Y_{CH_4/COD_o}	Yield of methane (m^3) per unit (kg) COD in the influent (COD_o) (Note b)	$m^3 \cdot kg^{-1}$
Y_{CH_4/COD_r}	Yield of methane (m^3) per unit (kg) COD satisfied (i.e. "removed") (COD_r) (Note c)	$m^3 \cdot kg^{-1}$

Y_{CH_4/TS_o}	Yield of methane (m^3) per unit (kg) total solids in the influent (TS_o) (Note b)	$m^3.kg^{-1}$
Y_{COD_r/COD_o}	Conversion - ratio of weight (kg) of COD "removed" (COD_r) to weight (kg) of COD in the influent (COD_o) (Note b)	$kg.kg^{-1}$
Y_{VS_r/VS_o}	Conversion - ratio of weight (kg) of volatile solids removed to weight (kg) of volatile solids in the influent (VS_o) (Note b)	$kg.kg^{-1}$

Note a. Weight basis (wet or dry) of substrate must be reported.
Note b. Retention time must be reported.

Note c. The theoretical value is 0.35 $m^3.kg^{-1}$. Differences between measured values and 0.35 should be interpreted.

C. Measurment and Analyses

1. Operating/Measurement Conditions - Probably more so than any other biological system, biomethanation systems in the field are subject to variations beyond the reasonable control of the operator. These include: variations in feedstock characteristics, composition, and content of toxic materials; major and minor fluctuations in ambient temperature; variations of post-digestion treatment of liquid/solid effluents; variations of storage conditions for both feedstock and effluent; and variations in rate of use of gas produced. Thus, the conditions under which measurements are made must be clearly stated if the results reported are to be meaningful.

   a. It should be clearly stated whether the results refer to a transient or steady-state condition.

b. The test procedure and results based on a steady-state condition are meaningful only if the digester conditions are maintained constant not only during the test period but also for a period prior to the test. Any variation in key parameters (e.g. temperature, feeding rate, pH, gas production rate) during the test must be recorded and reported.

c. As a matter of convenience, the time scale used for measurements is based on the mean retention time. It is commonly accepted that a steady state is not reached before at least two or three mean hydraulic retention times have elapsed under constant running conditions.

d. A test should, if possible, be carried out over several retention times. In any event, each test should be carried out over a minimum of two retention times, with daily (or more frequent) monitoring of key parameters and variables. In any event, averaged values over the entire test period should be used.

2. Sampling - Good sampling of slurries is difficult, since settling occurs rapidly. As a result, samples are not always representative of either the feedstock or the digester contents. Furthermore, the degree to which a small sample is indeed representative is greatly influenced by the number and size of particles or fibrous materials in the feedstock or digester contents.

a. It may be necessary to mill (grind) the material to be sampled, to insure that a representative sample is obtained.

b. Information on sampling conditions should be reported in sufficient detail to permit evaluation of the quality of sampling.

3. Analyses - Suggested analytical methods are listed in Table 5. Analyses should be made of both the soluble and the insoluble fractions, or their mixture, in the feedstock and the effluent, and of the gas and digester contents. If determinations are made on solid or liquid phases, the separation method and conditions of the analysis must be specified. When mean values are reported, the number of measurements should be indicated. (The alternative is continuous recording over a reported time span.)

4. Data to be collected by farmers - In most situations it will not be possible for the careful measurements and analyses described in this section to be made. Nevertheless, it is possible for the farmer, with a little effort, to obtain data that will give the technician useful information about the operation of the system. These data, and suggested methods for determining them, are described here.

   a. Daily loading of feedstock - The specific gravity of cow dung is close to 1 (1.05-1.1). Thus, if the quantity of dung is measured by volume, this can be taken roughly as equal to its weight (in a consistent system of units). This variable may be evaluated every season (four times/year), especially when the animal feed varies significantly. Other feedstock materials, such as poultry droppings and solid agricultural wastes, may be easily evaluated. In this case, the farmer uses a standard local measure for volume; the technician would merely need to weigh a measured volume to translate the farmer's measurement to loading rate.

b. Solids content of feedstock - Generally the solids content of the fresh cow dung ranges from 15 to 25% and varies with species, degree of drying, and mixing with bedding material or urine. An average value for the solids content for the local area should be known by the nearest laboratory center. Thus, by use of this value, the solids content of the feed material can be estimated accurately enough to evaluate digester performance. (For example, if the average solids content of local dung is 16%, dilution with water at 1:1 produces a feed slurry with a solids content of 8%.) A similar approach may be used with other feedstocks.

c. pH - The pH of the feed or the digester contents can be roughly determined by use of pH paper, which should be done periodically. In the event this indicates a trend toward acidity or in the case of a problem characteristic of acidity, $CaCO_3$, Na_2CO_3, $NaHCO_3$, CaO, ash, or other chemicals may be added to decrease the acid content in the digester, as needed.

d. Temperature of the digester contents - It is recommended that a suitable thermometer be installed near the middle of the digester at a known location. Then the temperature can be monitored frequently or in case of operational difficulties. If the temperature sensor is not fixed, a glass thermometer may be fixed inside a PVC tube in such a way that, when the tube is withdrawn for a temperature reading, the thermometer bulb remains immersed in some portion of the slurry. This technique would minimize the error in measuring the temperature.

e. Gas production rate - The gas production rate can be evaluated roughly by one of the following methods, according to the prevailing situation.

i. Floating gas holder - The amount of gas produced can be evaluated by monitoring the increase in height of the gas holder with time, during periods when no gas is used.

Gas production rate = increase in height (m) x cross section of the gas holder (m^2) x 24/time(hrs)

= $m^3 \cdot d^{-1}$

ii. Fixed-dome Chinese-type digester - The amount of gas produced can be evaluated by monitoring the increase of slurry level in the discharge outlet and the duration (for example, during the night), neglecting the change in volume of the gas related to the increase in pressure (generally not more than 10 % of the produced gas). Then, approximately:

Gas production rate = increase in the slurry level (m) x cross-section of the outlet (m^2) x 24/time(hrs)

= $m^3 \cdot d^{-1}$

This approach is useful with a digester whose inlet has a cross-sectional area much smaller than that of the outlet. If the two are comparable in size, a similar calculation must be made for the inlet chamber, and the two volumes added for an estimate of the gas production rate.

iii. For constant-pressure digesters - The amount of gas produced can be evaluated by measuring the duration of operation of gas-use devices and multiplying by their known capacities (volume of gas used/hour).

iv. Small and low-priced gas meters can be used, if available, by connecting them in the main gas line.

v. The gas production rate should be reported in m^3 per m^3 of digester volume per day ($m^3_{gas} \cdot m^{-3} \cdot d^{-1}$).

A simple table is prepared for reporting the information collected in the field:

Field Data Table

Digester charateristics:
1. Type
2. Volume
3. Location
4. Others

Date	Parameters/variables Measured						Remarks
	Daily feed to digester (liters or kilograms	Solids content[a] in feedstock (%)	Temperature °C		pH	Gas Production Rate ($m^3\ d^{-1}$)	
			Digester	Ambient			

[a] For field measurements, this would most likely be total solids (TSo), since this could be determined by simple drying.

Table 5 Methods That May Be Used to Obtain Analytical Data for Biomethanation Systems.
(The methods listed are examples. The list is not meant to be exhaustive, nor does it imply that the methods listed are the only ones recommended.)

Measurement	Methods
Total Solids (TS)	Oven: T=105°C until constant weight
Volatile Solids (VS), mineral matter and ash content (residue)	Oven: T=450°C for 12 hours, or 600°C for 3 hours. (Not always reliable because of varying losses.)*
Chemical Oxygen Demand (COD) (at least for more diluted wastes)	Standard methods. (With slurries, careful homogenization is required.)*
Ammonium Nitrogen (NH_4^+-N)	Distillation (pH)*; direct chemical measurement; electrode*
Volatile Fatty Acids (VFA) (C_2+C_3 to C_5)	Steam distillation and titration; gas chromatography; HPLC
pH	pH meter (pH changes with loss of CO_2*); litmus paper; pH indicating paper.
Total Alkalinity	Titration
Gas composition	CO_2 absorption; gas chromatography; infra-red spectrometry; mass spectrometry
Particle Size	Sieve
Volatile, or total, suspended solids (VSS or TSS)	Centrifugation and oven; filtration; decantation.*
Total Organic Carbon (TOC) (See note b, Table 4)	Special apparatus (expensive for homogenization, microdismembrator)*
Cellulose, Homicellulose, Lignin (interpretation*)	Van Soest or more specific
Starch	Hydrolysis plus sugar determination
Soluble Sugars	Chemical or enzymatic method; chromatography
Organic Nitrogen (See note c, Table 4)	Kjeldahl (total protein ?); total organic nitrogen
Biochemical Oxygen Demand (BOD) (for wastewater)	Winkler Respirometry (Interpretation*)
Bicarbonate alkalinity ([HCO_3^-])	Titration, CO_2 elimination + back titration
F_{420}	Fluorescence/Spectrometry
Amino acids and other nynhydrin-positive compounds, before and after hydrolysis	Ion-exchange chromatography; HPLC
Calcium, magnesium, sodium, and potassium	Flame photometry
Microbial mass or activity	ATP (interpretation*); F_{420};* specific enzymatic activity*; co-enzymes*; specific components*; dehydrogenase*; total protein content.
Biodegradable/ non-biodegradable matter	Batch digestion
Compounds toxic to micro-organisms	Bioassay tests
Pathogenic microorganisms and parasitic egg	Culture on specific media

* Interpretation of results is difficult, or method is difficult to use.

III. UTILIZATION, HEALTH, AND ENVIRONMENTAL ISSUES

The ultimate purpose of biomethanation systems is their usefulness to people. That usefulness involves the use of the products, uses that the system itself may serve, and most important, the socio-economic aspects of these uses, including the tangible and intangible impacts on a community. Thus, an examination of the use of the products is made first, followed by consideration of useful purposes served by the system, and a discussion of socio-economic issues and impacts.

A. Uses of the Products of Biomethanation

1. Energy Uses - In Table 6, the uses of the gas as an energy source are listed, together with recommendations of the parameters to be measured and the units in which these measurements should be reported.

Table 6. Energy Uses of Biomethanation Systems Outputs

Use	Parameter	Units
Cooking	Calorific value	$kJ \cdot m^{-3}$
	Methane content	% CH_4
	Rate of consumption[a]	$m^3 \cdot h^{-1}$
Lighting	Rate of consumption[b][c]	$m^3 \cdot h^{-1}$
Shaft power[d]	Rate of consumption	$m^3 \cdot h^{-1}$, $m^3 \cdot (kWh)^{-1}$
Refrigeration (absorption)	Rate of consumption[e]	$m^3 \cdot h^{-1}$
Process heat[f]	Rate of consumption[e]	$m^3 \cdot h^{-1}$
Space heating	Rate of consumption[g]	$m^3 \cdot h^{-1}$
Drying	Rate of consumption[h]	$m^3 \cdot h^{-1}$

Notes:
(a) Depends on efficiency of conversion.
(b) Meaningful only if related to light ouput (lumens) although qualitative comparisons to kerosene lanterns or electric lights are useful.
(c) Light output is not a normal field measurement.
(d) Includes electricity generation, transportation, milling, water lifting.
(e) Meaningful only if ΔT and C_p are reported.
(f) Includes domestic water heating.
(g) Depends on qualitative measure of comfort.
(h) Meaningful only in conjunction with ambient temperature (°C) moisture content (% water), and relative humidity (%).

In considering these uses, one should note that with one or two exceptions the parameters to be measured can generally be measured in the field, under normal conditions of use. The calorific value in joules per cubic meter normally cannot be measured in the field. It can be inferred, however, from the methane content, which can be determined precisely enough by measuring a given gas volume before and after the CO_2 has been removed by absorption in water (or limewater). In the case of shaft (mechanical) power, while the time rate of consumption can be measured in the field, the consumption per unit power output will generally be inferred from the nameplate rating of the device and estimates of its efficiency.

2. Agricultural Uses - Agricultural uses of the outputs of biomethanation systems are listed in Table 7, which also lists parameters to be measured and the units in which the measurements should be recorded. This table is based on the assumption that all measurements are made on a defined effluent system, *i.e.*, sludge (filtrate or settled solids), liquid (supernatant), slurry (liquid plus suspended solids after agitation of digester contents), or any combination of these. In addition, any treatment of this effluent stream, such as drying and comminution, must be clearly specified before the values of the measured parameters can be meaningfully interpreted by others. (See discussion on sampling and particle size in II.C.2. above.)

Table 7. Agricultural Uses of Biomethanation System Outputs
(All entries imply an initial definition of the effluent stream.
See Section II for a discussion of this and analytical techniques.)

Use	Quantity to be measured	Units
Fertilizer	Rate of use (dry weight basis)	$kg \cdot ha^{-1}$
	Nutrient content (dry weight basis): Available N[(a)], P, K	$g \cdot kg^{-1}$ or weight %
	Trace elements	$mg \cdot kg^{-1}$
	Toxic substances (dry weight basis): Toxic heavy metals	$mg \cdot kg^{-1}$
	Pesticide residues	$mg \cdot kg^{-1}$
	Viable seeds (each species)	number/kg, % germination
Soil Conditioner	Humus (dry weight basis)	% organic matter
Animal Feed	Rate of consumption (dry weight basis)	$kg \cdot d^{-1}$ per head, $kg \cdot ha^{-1} \cdot d^{-1}$ (for fish)
	Nutrient content (dry weight basis): Available Ca, P, fat protein, carbohydrates	$mg \cdot g^{-1}$ or weight %
	Vitamins	$I.U. \cdot g^{-1}$
	Trace elements	$mg \cdot kg^{-1}$
	Toxic substances (dry weight basis): Toxic heavy metals	$mg \cdot kg^{-1}$
	Pesticide residues	$mg \cdot kg^{-1}$
	Microbiological quality (pathogens, parasite eggs)	viable count per gram
Livestock Bedding	Microbiological quality (pathogenic, microörganisms parasite eggs)	viable count per g[illegible]

B. Uses of Biomethanation As A System

Biomethanation systems serve many useful purposes, aside from the uses of their products. These include health and sanitation, and ecological issues.

1. Health and Sanitation - In Table 8, the role of biomethanation systems in public health and sanitation is dealt with by identification of the parameters to be measured for three major aspects of this use, and the corresponding units for reporting these measurements are indicated.

Table 8. Public Health and Sanitation Aspects of Biomethanation Systems[(a)]

Use	Parameter (All parameters apply to all residues)	Units
Residue Treatment: Animal residues Domestic (human) residues Agricultural residues Industrial residues Forest rsidues	Rate of production	$kg \cdot d^{-1}$ or metric tons per day
	Rate of treatment	$kg \cdot d^{-1}$ or metric tons per day
	COD conversion[(b)]	%[(b)]
	BOD coversion[(b)]	%[(b)]
	Pathogen and/or parasite kill rate[(c)]	$\log \cdot d^{-1}$[(c)]
Water Treatment: (Removal of pollutants by biological means)	COD conversion[(b)]	%[(b)]
	BOD coversion[(b)]	%[(b)]
	Pathogen kill rate[(c)]	$\log \cdot d^{-1}$[(c)]
Vector control:[(d)]	Population	larvae per kg eggs per kg population per ha

Notes:

(a) See Tables 3 and 4 for detailed discussion of parameters and units.

(b) Conversion ratios would be measured where laboratory facilities are available. If only occasional monitoring of field installations is available, with no regular monitoring of the input, then measurement of BOD and COD of the effluent may be all that is practical.

(c) With no laboratory available to monitor the input materials, occasional monitoring of field installations would be confined to total viable counts of pathogens and parasites per liter of effluent.

(d) Includes insects and parasites.

2. <u>Ecological Uses</u> - In some countries, notably Indonesia, biomethanation systems are being used on an experimental basis to control the spread of noxious plants, such as water hyacinth, by harvesting them and using them as a feedstock. (This is distinct from the survival rate of viable weed needs in biomethanation effluents used as fertilizer.)

C. <u>Socio-Economic Issues and Social and Ecological Impacts of Biomethanation Systems</u>

The technical parameters and characteristics of biomethanation systems certainly play an important role in the acceptance and use of such systems. The technical questions are the first ones asked and preliminary choices are generally made on the basis of how well a particular design meets certain technical criteria. This is an inadequate basis for a choice, however, because more important than the technical characteristics of a system, in terms of acceptance and use, are the quantifiable economic costs and benefits, the quantifiable impacts on an ecological system, and the many intangible non-quantifiable costs, benefits, and impacts that a society experiences.

1. <u>Use of the Products of Biomethanation</u> - Conventional economic cost/benfit analyses take account of the tangible benefits and costs of the use of biomethanation products by considering such things as:

   o costs of energy sources supplemented or displaced by biogas

   o cost of transporting, distributing, and converting energy supplemented or displaced

   o cost of fertilizers supplemented or displaced by biomethanation residues

- cost of transporting and applying fertilizers supplemented or displaced
- cost of capital
- cost of labour
- cost of operation and maintenance
- cost of end-use devices.

a. Energy Uses - Generally not included in the choice of biomethanation systems to be promoted with public funds is the not easily quantifiable value (or cost) to society of the impact of this alternative energy source on:

- deforestation
- watershed management
- health and sanitation
- food preservation
- labour
- employment
- self-sufficiency
- human resources
- perception of status
- general quality of life.

A summary of these issues as they pertain to the use of biogas for fuel is presented in Table 9, which should be read in conjunction with Table 6.

b. Agricultural Uses - One of the primary benefits of biomethanation is the recycling of nutrients and humic materials. It is extremely important in an economic evaluation, however, that these benefits be accurately assessed in terms of the amount used relative to the initial amount of biomass from whi it was derived.

Table 9. <u>Use of Energy from Biomethanation: Socio-Economic Issues Check List</u>

Quantifiable aspects	Non- (or Not Easily) Quantifiable Aspects
<u>Fuels or systems displaced</u> (relative calorific value <u>vs.</u> cost): .Firewood .Charcoal .Crop residues .Dung .Other biomass systems - Gasification - Ethanol - Methanol[a] .Fossil fuels - Kerosene - Gasoline - Diesel oil - LPG .Electricity - Grid - Local generator .Water power (mechanical) .Solar energy - Cooking - Drying - Photovoltaics .Wind <u>Labor Costs</u> .Construction .Operation and maintenance <u>Capital Costs</u> .Digester .Gas storage and distribution <u>Cost of end-use appliances/equipment</u>	<u>Impact on:</u> .Food preservation (from cooking smoke and heat) .Insect repelling (from cooking smoke and heat) .Space heating side effects from cooking .Deforestation - Erosion - Water control - Water tables .Alternative use of limited labor pool .Employment generation - Construction - Collection of feedstock - Operation and maintenance - New jobs created by increased availability of energy .Employment displaced - Jobs associated with previous uses of substrate - Jobs displaced by new energy source .Human resources/skills - Availability of manpower for technical assistance, maintenance - Skills training needed - Education .Communication (public education required to encourage acceptance)

[a] Methanol production is not yet a commercial practice, but it is a laboratory and pilot-plant process.

There are many methods of recycling biomass in agricultural systems, not all of which involve anaerobic digestion. Typical handling methods are:

- o burning (with ashes left in the field);
- o direct application to the field;
- o direct application to the field, but plowed under the surface;
- o composting and application to the field;
- o digestion and direct application to the field; and
- o digestion followed by drying and then application to the field.

During all of these handling and treatment methods, the nutrients - the major one of interest being nitrogen - undergo certain chemical transformations and as a result may be lost from the biomass. Hence, from a given amount of biomass containing a certain quantity of nitrogen, the final quantity of nitrogen (organic plus ammoniacal) remaining depends on the method of treatment and handling. The effect of this nitrogen plus humic materials (and micronutrients and trace elements) should then be rigorously tested by long-term field trials. Increases in crop yields resulting from the recycling can then be economically evaluated in relation to a standard control and to certain quantities of chemical fertilizers, e.g., urea and superphosphate, and the appropriate numbers ascertained for the financial analysis. This approach will elucidate the economic consequences of the various handling and treatment methods for a given quantity of biomass that is recycled to the land.

These and other issues are summarized in Table 10, which should be read in conjunction with Table 7.

Table 10. Agricultural Uses of Biomethanation Residues - Socio-Economic Issues Check List

Quantifiable Aspects	Non- (or Not Easily) Quantifiable Aspects
Fertilizer Fertilizer/soil conditioner displaced (relative value vs. cost): .Dung .Crop residue .Forest residue .Chemical fertilizer .Night soil Effects on crop yields Labour costs .Transportation .Application Equipment Costs .Transportation .Storage .Application Income generation from sale of residues Energy Costs .Transportation .Processing .Application .Manufacture (of displaced fertilizer) Relative concentration of toxic substances	Impact on: .Self sufficiency .Human resources/skills - Availability of manpower for technical assistance, maintenance - Skills training needed - Education .Communication (education needed for acceptance and use) .Pollution - air - water - soil .Habitat for pests .Soil fertility and land value .Land carrying capacity .Employment generation - Handling, processing, storing residues .Employment displaced - Jobs associated with previous uses of feedstock .Safety (sanitation)
Feed Feed/fodder supplemented or displaced: .Crop residues .Commercial feeds .Fodder/forage Effect on yield/productivity Labor costs .Transportation .Packaging/handling .Storage .Use Equipment costs .Transportation .Storage Income generation from sale Energy costs .Processing .Transportation .Manufacture (displaced feed, if any) Toxic substances	Impact on: .Self sufficiency .Human resources/skills - Availability of manpower for technical assistance, maintenance - Skills training needed - Education .Communication (education needed for acceptance and use) .Pollution - air - water .Employment generation - Handling, processing, storage .Safety (sanitation) .Land carrying capacity

2. Use of Biomethanation System - By far the most important aspect of use of the biomethanation system is the impact on public health and sanitation. Socio-economic evaluation of this aspect of biomethanation is probably the most difficult, however. Some of the major points to be considered are listed in Table 11, which should be viewed as a supplement to Table 8.

Table 11. Public Health/Sanitation - Socio-Economic Issues Check List

Quantifiable Aspects	Non- (or Not Easily) Quantifiable Aspects
Capital cost (equipment)[a] Use of outputs[b] . Cost of use . Income generated	Human Resources . Availability of manpower for technical assistance, maintence . Skills training needed Communication (education needed for acceptance and use) Social organization needed for successful use of systems . Latrines . Night soil/dung collection

Notes:
(a) Allocation of these costs must be shared among other uses for biomethanation systems, because these systems would not be constructed solely for public health/sanitation purposes.
(b) These are the same as listed in Table 6 and Table 7.

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APPENDIX A.

Dr. Norman L. Brown, Equity Policy Center

GENESIS OF THIS WORKSHOP

Although biomethanation systems have been in use for many years in many parts of the world, the lack of a systematic way of reporting the results of experimentation with, and use of, such systems has made comparisons among them and their relative evaluation extremely difficult. This problem arises from the lack of agreement on parameters and variables to be measured, the conditions of measurement, and even the units of measurement. Compounding this confusion is the fact that there exists no basis for cost comparisons because different direct costs are usually reported, and many important indirect costs, such as taxes and subsidies, are frequently not taken into account.

This workshop was organized, therefore, to attempt to bring some order to this situation by agreeing on a systematic scheme for reporting technical measurement--quantity to be measured, units in which to express the measurements, and conditions under which the measurements are made--and emphasizing the overriding importance of socio-economic issues, which ultimately determine the use and acceptance of biomethanation systems. The objective is to make easier the task of the decision maker who must decide on allocating part of a national budget--and scarce resources--to energy systems, by providing a coherent, rational data base to the technical advisors who are called upon for advice and information.

Dr. S.J. Tőrok, Energy Section, Division of Natural Resources, ESCAP

The ESCAP secretariat would find it useful if the results of the workshop are presented in the form of a "map" or a "matrix" characterizing biomethanation systems with objectives on the horizontal axis and listing relevant parameters on the vertical axis. Details such as measurement units and possible descriptive material for the measurement process would be place3d within the matrix.

For each objective of the matrix, or within each objective, for each type of digester, a "diagnostic chart" would be useful to assist operators in monitoring "normal ranges" and "abnormal operations" for critical parameters.

It should be emphasized that while the map or matrix itself may be of use for designers and researchers, the set of diagnostic charts should be useful for technicians in the field for monitoring and diagnostic purposes.

Finally, the products of the workshop will be tested in late May at a training seminar in Chengdu, China.

Prof. Dr. M.A. Hamad, National Research Centre, Egypt

REPORT ON BIOGAS TECHNOLOGY IN EGYPT

In 1978, the National Research Centre (NRC), Cairo, started a national research, development, and demonstration programme to assess the viability of biogas technology in rural areas of Egypt. The village demonstration phase, which is the central focus of the whole programme, was preceded by a multi-disciplinary research, development, and in-house demonstration phase.

Three prototype units have been built near the NRC for experimentation; these units are of the Chinese and Indian style.

In May, 1981, two demonstration units were built in Manawat village near Cairo. One is a modified Chinese-type digester (10 m^3) and the other is a modified Indian type of the same volume.

In March, 1982, three units ranging in volume from 5 to 10m^3 were built in Omar Makram village, which is one of the new villages built on reclaimed desert land. One of these units is a small community unit that serves two families. The second unit is a modified Chinese-type digester connected to the latrine as well as the animal shed. The main modifications in this unit are:

1. The slurry is forced out by the pressure of gas rather than manual addition of feedstock.
2. Constant gas pressure is achieved by using a simple available controller, resulting in reduction of gas losses.

In January, 1983, a large unit of 50m^3 capacity was erected in Shubra Kas, near Tanta. The digester is a tunnel type with a separate gas holder. The temperature of fermentation is controlled automatically; external heating is provided by using a portion of the biogas generated. A passive solar-heating system is also installed. The unit operates on poultry droppings, and the gas produced is used for heating the poultry house, replacing LPG.

The community unit suffers from many difficulties, most of which are sociological problems, reflecting the unacceptability of the community-unit types in Egyptian rural areas.

Both the Indian and Chinese family-size digesters suffer from many limitations with regard to their appropriateness. Therefore, there is a question about a deficiency in their potential use under Egyptian conditions. These limitations may be summarized as follows:

1) Fluctuation of the slurry temperature depending on the season - This leads to a sharp drop in the gas production during the winter season.

2) The relatively large underground depth needed - This causes construction difficulties because of the presence of a high water table in most of the rural areas.

3) The presence of relatively large amounts of dead space - This results in lower conversion efficiencies.

4) Both types of digesters require a comparatively large area for construction of the unit and effluent treatment, which may not be available in most rural houses.

In order to overcome these major difficulties and limitations, NRC is carrying out an R&D programme aimed at developing a solar-heated digester suitable for the Egyptian situation.

Dr.Prakasam B.S. Tata, Research and Development Laboratory
Metropolitan Sanitary District of Greater Chicago, U.S.A.

The production of methane from organic waste materials by anaerobic digestion is a well known phenomenon. The various transformations involved in the conversion of organic waste materials to methane can be optimized if a conducive environment is provided for the growth and maintenance of the organisms that are involved in bringing about these transformations.

Information exists on the nature and behavior of the various microorganisms responsible for anaerobic digestion of wastes under different environmental conditions. The design of various types of biogas systems is based on this information for application in either the rural areas of developing countries or the metropolitan areas of the developed parts of the world. It is neither the diligence nor the integrity of the microbial population that should be questioned when a properly designed biogas unit does not perform well in the rural areas of developing countries. What should be questioned is whether a proper educational programme was carried out initially and followed up subsequently to make the villager or the community understand and follow the recommended procedures to operate the digesters satisfactorily and to accept them wholeheartedly.

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Dr. Roberto Cáceres E., Bioenergy Project

Organización Latinoamericano de Energia (OLADE)

THE BIOENERGY PROGRAMME OF THE LATIN AMERICAN ENERGY ORGANIZATION (OLADE)

OLADE is an intergovernmental Latin American and Caribbean organization based in Quito, Ecuador. OLADE's objectives are to increase regional energy cooperation, national energy self-sufficiency, and regional technological autonomy. OLADE's activities are in energy planning, oil, coal, hydroenergy, geothermal energy, bioenergy, wind, and solar energy.

The bioenergy programme is working on fuelwood, charcoal, gasification, alcohol, and biogas in 16 countries with the cooperation of FAO, the Interamerican Institute for Cooperation in Agriculture, ECLA, GEPLACEA (the association of sugar producers of Latin America and the Caribbean) and other regional and international institutions.

The biogas project started in 1979 with demonstration models of Chinese, Indian, horizontal, and Guatemalan semi-dry batch digesters in rural areas of Guatemala, Honduras, Nicaragua, Haiti, the Dominican Republic, Grenada, Guyana, and Ecuador. A recent evaluation found that 70% of the biodigesters are still in operation. Efforts continue to improve the efficiency of rural digesters.

In addition, OLADE has programmes:

- To design a continuous process of evaluation, standardization, and follow-up of the biodigesters installed
- To promote the use of revolving funds for financing the diffusion of the biodigesters
- To increase the technical capabilities in biomethanation of existing energy institutions for development

- To build mechanisms for coordination at the national level between energy and agriculture sectors for supporting long-term national biogas programmes, especially in the agriculture/rural extension services

- To support a Latin American Biogas Network, with the cooperation of FAO and other international agencies and the participation of the Latin American institutions most experienced in biogas, including:
    - Empresa Brasileira de Tecnológia Rural (EMBRATER), Brazil
    - Centro Mesoamericano de Tecnológia Apropiada (CEMAT), Guatemala
    - Instituto de Investigación Tecnológica Industrial y de Normas Técnicas (ITINTEC), Peru
    - Instituto de Investigaciones Eléctricas (IIE), Mexico
    - Instituto de Pesquisas Tecnológicas (IPT), Brazil

  and other biogas units of the energy, agriculture, environment, health, and science and technology sectors of Latin America and the Caribbean

- To promote the utilization of new techniques of biomethanation by agroindustries: sugar mills, coffee plantations, and livestock farms

Prof. Henri P. Naveau, Université Catholique de Louvain

The Commission of the European Communities (CCE) supports research, development, and demonstration projects in several programmes. Under the Research and Development Programme, "Recycling of Urban and Industrial Wastes," twenty contracts have been awarded dealing with biomethanation of manure, agro-industrial waste and wastewaters, and urban solid wastes. A coordination activity has also been organized that resulted in a "proposal for the definition of parameters and analytical measurements applicable to anaerobic digestion." This work will be expanded to deal with analytical methods.

In the "Solar Energy" Programme (group E, "Energy from Biomass"), six contracts have been awarded for study of biomethanation of manure, algae, and wastewaters, and a survey of biogas plants in Europe is taking place. Research, Development, and Demonstration projects are also partially funded by the Commission under the sponsorship of the European Fund for Development (FED).

The Unit of Bioengineering of the Catholic University of Louvain, Louvain-la Neuve, Belgium (Profs. E.J. Nyns and H.P. Naveau) conducts research and development work on biomethanation: parametrization, second generation systems (two-stage biomethanation of solid substrates such as algae or urban solid wastes, fluidized-bed biomethanation of wastewaters), fermentation pattern and its influence on process choice, and regulation and modeling of digesters (with Prof. Installe). The Unit is also setting up a laboratory and field digesters in Burundi, Africa. The staff of the laboratory is fifteen scientists and includes students from various countries.

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Dr. Rolf T. Skrinde, P.E., Olympic Associates, U.S.A.

BIOMETHANATION EXPERIENCE IN THE UNITED STATES OF AMERICA

As in many other countries of the world, the development of biomethanation in the United States began six to seven decades ago in the anaerobic fermentation of sewage sludge. The biogas produced in those wastewater treatment facilities was utilized to heat the digesters amd waste-treatment plant buildings, and in large plants provided shaft power for operation of the digester and even electricity for local use. A great deal of research and development has therefore been done on anaerobic fermentation at universities, operating facilities, and government research centers in the United States.

Since the early 1970's, there has been an acceleration of biomethanation development in the United States, with both research and operating-facility construction proceeding hand in hand. The impetus for this accelerated development has been energy production, but in the experimental processes a number of additional benefits of anaerobic digestion have been elucidated.

Various feedstocks and processes have been studied. One of the most common feedstocks has been animal manure, while others have included garbage and refuse, agricultural residues such as corn stover, food processing wastes, and certain other industrial wastes.

One of the most interesting areas of biomethanation development has been in process design. A great deal of research has been done, and is still in process, that has reduced the retention times in the digesters, and thus costs. Retention times of 30 days some years ago have now been reduced to as little as two days.

Some of the benefits of anaerobic digestion that have been developed in addition to energy are the value of the digested slurry as re-feed to cattle and hogs, the fertilizer value, and pollution control. Results of the studies are well documented in the literature.

Most biomethanation facilities in the United States that have been constructed recently have been for treatment of animal manure and certain industrial wastes. There are also a few small-size biogas plants that have been constructed for experimental purposes and for use by environmentally concerned and innovative persons.

In the United States, the cost factors of biomethanation plants presently favor the larger facilities. It is anticipated that, as lower-cost facilities are developed and fossil-fuel costs rise, there will be a large increase in the number of smaller, family-size biomethanation facilities in the United States during the next decade.

B.R. Deolalikar, A.T. International, U.S.A.

A.T. International is a Washington-based development organization working in the field of appropriate technology (AT). It supports small-scale projects undertaken by local organizations in over 30 countries in Africa, Asia, and Latin America. These projects cover such technology fields as food processing, utilization of agricultural wastes, local mineral resources utilization, and other fields. The emphasis is on utilization of local resources to generate employment, production, and services.

The importance of biomethanation systems in an AT context is in terms of their relevance in energy utiliztion for productive purposes; agricultural uses, as fertilizer and feed; and public health, sanitation, and environmental impact. The standardization of the technical and socio-economic parameters of biomethanation systems should result in facilitating the utilization of these technologies and their access by poor farmers.

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U Thet Zin, FAO Regional Office, Bangkok

STATEMENT OF THE FAO REPRESENTATIVE AT THE WORKSHOP ON UNIFORMITY OF INFORMATION REPORTING FOR BIOMETHANATION SYSTEMS

Bangkok, Thailand, 2 - 6, May 1983

Mr. Thet Zin referred to the Resolution of the FAO Regional Conference, Jakarta, 1982, on the New and Renewable Sources of Energy for Agricultural and Rural Development. He mentioned that energy is one of the priority areas of the FAO programme of activities.

FAO is currently involved in development and training activities in biogas and also in producer gas. The FAO/UNDP regional project on improving soil fertility through organic recycling has undertaken several activities in biogas, particularly in China. FAO had the first regional consultation on producer gas from agricultural residues in China and the Philippines last June 1982. The second consultation in this area is scheduled to be held in Malaysia and Thailand this year.

So far, FAO has published several documents relating to biogas and producer gas technology.

Upali S. Kuruppy, UNESCO Regional Office for Science and Technology for Southeast Asia, Jakarta

In the field of energy, UNESCO concentrates on three main areas: research and development on the use of alternative energy sources; the setting up of a global Energy Information Network especially for New and Renewable Sources of Energy (NRSE); and attempting to provide the facilities required to train the various categories of personnel needed to tap the potential NRSE. The main alternative energy sources of interest to UNESCO are: solar, wind, geothermal, ocean, and biomass (including fuel alcohol).

In the Southeast Asia region, UNESCO has launched a Regional Programme within which five Regional Networks have been established. Two of these are interested in biomethanation systems. They are the Network for Development of Alternative Sources of Energy and the Network for the Utilization of Rural and Urban Wastes.

These Networks organize activities such as workshops, seminars, training courses, cooperative R&D projects, the publication and dissemination of directories, proceedings, and newsletters, and receive some support from UNESCO toward these. In other regions similar activities are promoted by UNESCO, although the actual mechanisms for implementing them may vary.

UNESCO would like to see a recommended reporting procedure as an outcome of this workshop so that the task of comparing and evaluating different biomethanation systems would be made easier.

Dr. Xu Zeng-Fu, Zhejiang Research Institute for Biogas and Solar Energy
Hangzhou, Peoples Republic of China

BIOGAS ACTIVITIES IN CHINA

The development and utilization of biomethanation systems in China began in 1930, when Mr. Luo Guorui obtained a patent for his biogas production technique from the Chinese Government and set up a gas company with branches in 13 provinces. In an effort to supply the fuel needed by peasants, biogas was once again generated and used extensively in the 70s. There are more than 6.5 million family biogas digesters of 8-10 m^3 each in the rural areas, benefiting about 30 million peasants, and about 700 small biogas motive power stations totaling 9,000 horsepower, both to generate 5,000kW electricity and to dry agricultural products.

Producing and using of biogas is a matter of mass drive. It has been developing rapidly and extensively. Although it has been bringing about marked results in certain districts, the development is unbalanced both in quality and quantity. Shortcomings and imperfections are unavoidable. People are striving to make improvement everywhere; especially since 1979, the quality of the newly built digesters has improved due to changes in the method of construction. The biogas administrative units pay more attention to repair or reconstruction of the so-called ill digesters. As a result, the peasants welcome the use of the biogas digesters again. (In Zhejiang province, there are more than 390,000 digesters, about 85% of which are in normal operation.)

Owing to the multi-function of biogas construction, the biomethanation systems must be viewed in their totality. What is important is not only the design and operation of the digester, but also the optimization of facilities for feeding, discharging, and distribution of gas and residues, and the comprehensive utilization of the products. One lesson of China's experience is that we cannot derive great economic benefits from biogas systems unless we make comprehensive utilization.

U Tin Hlaing, Agriculture Corporation

Rangoon, Socialist Republic of the Union of Burma

Burma is basically an agricultural country, and is now embarking on a programme of industrializsation based on agriculture. In the process of its effort to promote the economic and social well being of all of its citizens, the government has launched a number of action programmes in various fields. In the field of energy, Burma is self-sufficient in petroleum, and has potential reserves that warrant further exploration for petroleum and natural gas. However, it is still difficult to supply electricity, petroleum, and natural gas to the rural areas. The people in rural areas are still very much dependent on firewood for fuel. In recent years, the government has launched a programme to conduct research on biogas systems that can be suitably introduced in different parts of the country.

The Agriculture Corporation of the Ministry of Agriculture and Forests took the initiative in conducting research and extension works in this field. The research and pilot works started in Burma in 1974-75, but activities became more pronounced in 1980-81. In 1982-83, a special project on biogas was formed by the Ministry of Livestock Breeding and Fisheries. Since then, a series of training workshops on biogas systems has been initiated to encourage extension of the programme to the rural areas. The essence of the training is to give the trainees the technology of biogas production and utilization as well as an understanding of its impact on the social and economic aspects of rural areas. The biogas programme is now expanding rapidly in Burma, and in the very near future it may provide a partial solution to the problem of energy requirements of rural areas.

Sompongse Chantavorapap, National Energy Administration, Bangkok

BIOGAS IN THAILAND

Biogas technology was introduced in Thailand in the seventies. There are now about 3,000 individual biogas digesters and another 3,000 community-size digesters in the country, most installed within the last four years. It is estimated that 70% of them are functioning.

The National Energy Administration, Ministry of Science, Technology, and Energy, has already implemented a broad-based programme on biogas in cooperation with other agencies, among which are the Health Department, the Public Welfare Department, and the Agricultural Extension Department. About 1,000 biogas digesters are currently being installed each year. A programme to install 25,000 small-scale biogas digesters and 500 community-scale biogas systems within 5 years is being prepared.

Prof. Otto Soemarwoto, Padjajaran University, Bandung

SOME COMMENTS ON BIOGAS IN INDONESIA

Only a few biogas plants have been built in Indonesia thus far, and not all are running. There seems to be no real pressure and enthusiasm for biogas. The reasons for this are that Indonesia is an oil-producing country, kerosene is subsidized, many organic residues (twigs, dead wood, corn, and cassava stalks) are available, and the cost of the digester is high, particularly in relation to the income of the rural people.

The Institute of Ecology of Padjadjaran University at Bandung has started experiments with biogas production using aquatic weeds, especially water hyacinth, as the feed. Water hyacinth is a noxious weed in many lakes, water reservoirs, irrigation canals and rivers, causing serious damage in reduced reservoir-storage capacity, increased maintenance costs of irrigation canals, and interference with recreation and water transportation. It has a very rapid growth. The many efforts to control it have been costly in money and labour, and have met with little success.

On the other hand, the villagers are growing water hyacinth to clean their water supply from open ponds. The ponds have a multipurpose function, and serve for fish production, as domestic water supply, and as bathroom and toilet. When there is excess growth of water hyacinth, the villagers remove it and do not use it.

The objectives of the experiments are:

1. To control water hyacinth by utilizing it for biogas production.
2. To devise a recycling system in the rural water-treatment method by using water hyacinth for biogas production.

The digesters are built at a lakeside where water hyacinth grows abundantly. The cylindrical digesters are built of ferrocement with a steel floating gas holder. The sizes are 1,000 liters, 2,000 liters, 5,000 liters, and 10,000 liters. The water hyacinth is chopped immediately after harvesting and 20 to 30 kg of freshly chopped water hyacinth are fed into the digester every two or three days, when gas production starts to decrease. At the beginning, cow dung is added as a starter, after which only water hyacinth is used as feed.

The 1,000-liter plant produces 600 liters of gas, with a methane content of 60 per cent per kg (dry weight) of water hyacinth. However, with the larger digesters, less gas is produced per unit feed, presumably because of excessive scum formation. The mixing of the material in the digester is carried out simply by rotating the gas holder back and forth. With larger digesters this operation becomes increasingly difficult.

Dr. D. Stuckey, International Reference Centre for Waste Disposal

For the past 18 months, the author has been collecting and reviewing a large amount of literature on biogas in developing countries, and has prepared two reports for the World Bank. One of the objectives of this reviewing process was to identify various technical, economic, social and institutional factors that need further work in order to enhance the viability of the technology. These factors are listed below, and it is hoped that through their indentification further work will be oriented towards resolving some of the issues.

In the technical section of the report a global perspective is taken and an attempt has been made to list the factors in order of priority. However, depending on local enviroments these priorities may alter radically.

1) Standardization of data collection--While there is a considerable amount of data in the literature on the performance of anaerobic digestion systems, they are often poorly reported, inconsistent, and based on weak experimental design. A manual needs to be prepared by a consensus of biogas experts outlining standard experimentation and data reporting procedures, so that data obtained using different techniques and feeds in different parts of the world can be compared more easily.

2) Lack of substantive data on existing units--Despite the large number of units presently operating in developing countries, there is still a lack of consistent, rigorous technical data on the performance of existing fixed-dome and floating-cover designs under a variety of conditions. This information is needed to provide a baseline on which to assess promising new techniques and to carry out optimization exercises.

3) Optimization of existing units--In the past there has been little attempt to optimize rationally digester construction and operation. Available data should be used to optimize gas production and reduce capital cost. This procedure should be further refined by new data obtained from 2).

4) Digestion of wastes other than animal manure--There are not enough data currently available on the full-scale--*i.e.*, $>4m^3$-- digestion of many agricultural residues, aquatic plants, and industrial wastes. These data are needed to demonstrate the fact that other sources of biomass besides animal manure can be digested, and will assist in assessing the energy potential available from the current stock of biomass. In these studies the effect of such parameters as C/N ratio in the feed and the resulting effective C/N ratio should be investigated to determine the range of optimal ratios. In addition some experiments should be carried out on mixed substrates to determine any synergistic or antagonistic effects.

5) Evaluation of promising new techniques--In recent years there has been little attempt to evaluate and "unpackage" promising new techniques in digestion, *e.g.*, dry fermentation, bag, plug flow, filter and ABR. These techniques should be assessed at the pilot-plant level and compared to existing designs. If they are more effective, then every attempt should be made to diffuse them in developing countries.

6) Fertilizer/soil conditioning properties of the slurry--Due to the considerable uncertainty that exists in this area, experiments should be carried out to monitor closely the fate of nitrogen during different handling schemes. In addition, long-term comprehensive tests should be carried out on the effect of the slurry on crops yields in contrast to commercial fertilizers, and these results should be related to a fixed amount of fresh biomass before digestion. Obtaining these data will resolve some of the controversy surrounding the question of economic viability of biogas units.

7) Health effects of biogas--To substantiate the relatively sketchy data in the literature about the die-off of pathogens during digestion and subsequent handling before application to the field, the fate of pathogens during the processes should be monitored in existing units. Also, the effect of high NH_3 concentration at low C/N ratios should be evaluated to see if this leads to greater pathogen destruction. In addition, the health benefits of using biogas should be more closely quantified.

8) Refeeding dried slurry to animals--Due to its economic implications, especially with large-scale units, further work should be carried out on the effect of refeeding dried slurry to a variety of animals to see if it is an economic substitute or complement for commercial feeds.

9) Mixing--There is little information available on the effect of mixing on retention time and performance of digesters in developing countries. Studies should be undertaken to determine the actual retention time in typical digesters in developing countries, and how this can be improved by the judicious use of mixing.

10) Heating--Both composting and solar (passive and active) methods appear to have considerable potential in raising digester operating temperatures without large capital investments. More information is needed on these systems with regards to optimum design and their effect on overall digester performance.

11) Pretreatment--While this process has the potential for substantially increasing gas yields, few data are available on optimum precomposting conditions or physical size reduction. Hence, experiments should be carried out to quantify the effect of pretreatment on process performance.

12) Integrated resources-recovery methodology--This should be further refined to include considerations of food, and a number of pilot projects in different ecological zones should be carried out to enable more general guidelines to be established.

The Economic, Social and Institutional section takes into account the following factors (order does not indicate priority as the factors are interrelated and of equal importance):

1) While considerable information is available on the economics of biogas in India, most of it relates to household units with a floating-cover design, utilizing cattle dung. Rational policies towards biogas technology require more authoritative economic data and analysis based on actual operating experience under realistic conditions, and involving a wider range of:

i) designs and operating procedures,

ii) digester inputs,

iii) end uses for the gas and slurry in the domestic, agricultural and industrial sectors.

2) There appears to be a particular shortage pf good data and analysis of:

i) large-scale commercial plants (industrial and intensive animal rearing);

ii) integrating resource-recovery systems in which biogas plays a part (*e.g.*, systems existing in Israel, the Philippines, and China).

Such data should be obtained from experience in developing countries rather than from attempts to extrapolate developed-country experience.

3) Existing economic analyses of biogas are either methodologically weak, or are based on such special assumptions that comparison of one study with another is impossible. This problem of comparison is even more acute when a range of energy-conversion devices to satisfy a particular end use is considered, as in a national energy policy. There is, therefore, an urgent need to generate a broad consensus among analysts over the methods to be used in such comparative studies, with the particular emphasis being placed on the choice of technologies to satisfy a particular end use.

4) There is little understanding or empirical evidence concerning the factors likely to affect the diffusion of biogas technology. Such evidence might include the identification of peoples, locations, and other factors that might favour adoption e.g., the ownership of suitable inputs, adequate income, isolation from alternative energy sources, social structures that favour cooperation, credit, extension, and government policy.

5) The existing processes of research, development, and diffusion related to biogas systems appear to have been particularly weak and little understood. Genuinely scientific research has only recently been applied to small-scale plants and a surprising lack of knowledge still exists about many of the processes. This suggests that there are many lessons to be learned from detailed case histories of biogas research and diffusion, about the role of R and D, the role of implementing agencies in this and other attempts at non-agricultural rural technical change, and the development of indigenous technical capacity.

Prof. E. W. Rugumayo, Makerere University, Kampala, Uganda

Biogas was first produced in Africa in the early '40s. In 1963, Boshoff began scientific experiments in Uganda. Starting in 1973, the number of countries involved in research had expanded to include Botswana, Ethiopia, Kenya, Lesotho, Malawi, Tanzania, Zambia, and Zimbabwe, as well as Uganda.

In 1979, the Commonwealth Science Council (CSC) agreed to assist a number of African countries to promote research on new and renewable energy sources. Since then, biogas has been one of the energy sources on which research has been conducted under the CSC/African Energy Program (AEP). The Report (1982) of the Regional Workshop on "Development of Test Methods and Standards for Renewable Energy Technologies" noted that there are no agreed procedures for evaluating biogas digesters in Africa. There cannot be an effective way for biogas research information exchange and technology transfer and use within the Africa region until such standard methods are established. Suggested standards being discussed among members of CSC/AEP may provide a starting point for this workshop as it identifies reporting criteria for worldwide use.

(The following paper was submitted by H. R. Srinavasan, Gobar Gas (Biogas) Scheme, Khadi & Village Industries Commission, Bombay, India, who was unable to attend.)

INFORMATION FOR THE PURPOSE OF EVALUATION AND STANDARDISING CRITERIA FOR RENEWABLE ENERGY SYSTEMS

TECHNICAL

Digester

Type of digester: Floating dome

Floating-dome type digesters of the KVIC model are constructed below ground level. Digesters can be constructed of masonry (either brick or masonry), reinforced concrete, or ferro-cement, acording to the sub-soil condition and availability of materials locally. The floating dome for storing gas is fabricated from mild steel sheets, fibre glass or high-density polyethelene (HDPE). The delivery pressure of the gas is fixed at 10" water column. Floating-dome type KVIC model digester can be classified as a semi-continuous digester wherein the daily inputs are displaced through the outlet daily, after the specified retention period. This digester can also be used for batch-type digestion wherever materials other than animal waste are fed into the digester. However, the digester must be emptied manually to be cleaned.

Size:

The size of the digester is fixed by deciding the retention period, solid percentage of the slurry, and subsoil conditions.

Retention time:

Retention time is fixed taking into account the ambient temperature of the different regions. If the temperature throughout the year averages 25 to 30_{o}C, a 30-day retention period is used; if the average temperature is between 20 and 25_{o}C, a 40-day retention period is used; and if the average temperature is below 15_{o}C, the retention period is fixed at 55 days. The digester volume also depends on the solid percentage of the organic materials subjected to fermentation. In the floating-dome type an 8% solid percentage is assumed.

Materials of construction:

Brick masonry, stone masonry, reinforced cement concrete or pre-cast ferro-cement, <u>etc</u>., are used depending upon the local sub-soil conditions and the availability of local materials.

Range of ambient temperature:

Gas plants are constructed taking into account the ambient temprature of different regions. Broadly this can be grouped into 3 categories i.e. less than 15^{o}C, 15 to 25^{o}C and 25 to 30_{o}C.

Range of temperature of operations:

Gas plants are operated at ambient temperature. No heating of digester or pre-heating of inputs is proposed, since it may increase the cost of the plant. Since the temperature goes down for a period of one or two months at most in tropical areas, there may not be any need to heat the digester.

Organism:

The materials subjected to fermentation in biogas plants are mostly cellulose and hemi-cellulose materials such as animal dung and human excreta.

Others:

Installation of the digester below ground level helps in maintaining higher temperatures and the inputs can be fed by gravity flow, which will avoid the use of pumps or the necessity of lifting materials to a higher level, as would be the case with above-ground digesters. The gas plants constructed below ground level are cheaper than the plants constructed above ground.

Substrate

Type:

In the KVIC-type biogas plant, organic materials such as human excreta, animal dung, etc., can be fermented for the production of gas. The effluent is used as good organic manure. Some preliminary studies conducted by the National Dairy Research Institute, Western Region, Bombay indicate that the organic manure can be mixed with fresh cattle feed up to 10 to 20% as it contains many nutrients.

Proximate analysis:

The analysis of the effluent of biogas plants fed with manure indicates that it is rich in humus and contains 1.7 to 2.2% nutrients.

Water requirements:

Digesters that are in use in India are mostly of the continuous-operation type wherein the effluent automatically comes out through the outlet pipe as the input is fed through the inlet pipe. To make this arrangement function properly it is necessary to keep the daily input consistently at 8% solids.

Outputs

Gas:

The average gas production per kg of fresh cattle dung varies from 0.036 to 0.056 cubic meters. This may be due to the type of feed fed to the cattle. In the case of poultry droppings collected from the cages, the gas production was observed to be as high as 0.07 cubic meters. The other material use is human excreta. The average gas production observed is 0.042 cubic meters depending on the availabilty of substrate materials, size of digester, etc.

Residue:

The gas contains 52 to 60% methane, with the remainder being carbon dioxide with traces of hydrogen sulphide.

Distribution systems:

The gas container fixed on the top of the digester is designed in such a way as to hold the gas depending upon the rate of its use. A higher storage capacity required by limited use is provided by increasing the volume of the gas container; the delivery pressure of the gas is kept at 10" of water. Gas can be supplied up to a distance of one or two kilometers without the help of any booster. However, to maintain the gas pressure it may be necessary to use a larger diameter pipe for a longer pipe line, and this may be expensive. The gas used is not metered since suitable cheap gas meters for domestic use are not available in India. However, the availability of the gas supply is regulated depending upon the time most of the village houses/individual families need it--for example, for cooking or other purposes. Storage of gas under pressure in cylinders could not be attempted in view of the very low liquefaction point, i.e., minus 165°C.

Others:

To avoid a costly pipe line, the gas holder can be installed at different places depending on the concentration or clustering of points of use.

ECONOMIC

Costs

Digester:

The cost of the digester roughly works out to between Indian Rupees 600/- and 700/- per cubic meter of digester volume.

Substrate:

The substrate is not purchased by farmers; plants are installed by farmers who have their own cattle and that produce the required quantity of dung. Similarly, water is obtained from their normal water supply. For these reasons it is difficult to assess the cost. However, a community biogas plant arrangement was found to be not economically viable because of the need to purchase materials and water for feeding the plant.

Distribution/storage system:

The distribution system will be very expensive if the points of use are very much scattered. At times it may be economical to construct individual gas plants, thereby avoiding laying of long and costly pipe lines.

Benefit:

In most parts of a developing country, the fuel used in the domestic sector is biomass. In view of the inefficient ovens/stoves for burning wood, cattle dung cakes, etc., consumption of biomass materials is very high leading to rapid depletion of forests. In the case of the use of cattle dung cake, valuable fertilizer is wasted by being used as

Since biogas plant residue (fertilizer) is rich in humus, crop yield increases of about 30% are reported as compared with the use of ordinary composted manure. Apart from this benefit, it is observed that using biogas for cooking extends the life of household utensils beyond the life of utensils used for cooking with biomass fuel such as wood and dung cake. Similiarly, the frequency of painting the house can be prolonged to 4 to 5 years, compared to once a year if biomass fuels such as fire wood, cattle dung cake, etc., are used for cooking. The cooking time is also reduced to less than one hour when compared to the cooking done by using biomass fuels. Because biogas fuel is non-smoky, diseases such as bronchitis, eye diseases etc., are also minimized.

SOCIAL

Costs:

The time for collecting the substrate is negligible as the biogas plants are constructed mostly by individual farmers who own cattle. No additional labour is involved since they have to remove the cattle dung from the sheds to compost pits daily. Thus, feeding the biogas plant will not involve additional labour and cost. There are no cultural barriers in handling organic manure, particularly animal waste, except in the case of human excreta, about which there are some reservations in some parts of the country in view of the caste system.

Benefits:

Anaerobic digestion and proper disposal of organic wastes, particularly animal waste and human excreta, minimize pollution in the villages. Since biogas fuel is very efficient and non-smoky, the cooking time is reduced and thereby the drudgery of the housewife is reduced. Similarly, diseases such as bronchitis, eye diseases, etc., are also minimized.

Nutritional status:

Available reports indicate that about a 30% increase in the crop yield is noticed. However no study has been conducted on the nutritional value of the products produced by using the organic manure (residue) from biogas plants.

On an average, each family saves about two hours per day in collecting fuel wood.

About 2 to 3 hours cooking time is saved per day. Large-scale construction of biogas plants may minimize deforestation, soil erosion, and other related effects.

Since biogas fuel is an indigenous product, countries that import fuel, particularly petroleum fuels, can save foreign exchange.

(The following paper was submitted by Dr. Van-Vi Tran, ESCAP Secretariat)

DEVELOPMENT OF BIOGAS IN VIET NAM

1. Trends of Research

Research on the development of biogas in Viet Nam is carried out by a team of scientists under the leadership of Dr. Tran an Nhan of the Energy Research Section of the Development, Research and Pilot Centre, Hochiminh City. Its aim is to develop and design digesters appropriate to the environment and the economic situation of a developing country such as Viet Nam.

Thus, the requirements for a model digester are:

- o Simplicity in design and operation
- o Availability of construction materials
- o Low investment.

2. Continuous-type Digesters

2.1 Model digester

Research on the model digester is based on the following characteristics:

- o Tropical temperatures facilitate the decomposition of organic matter; thus, the ratio of surface to volume of the digester should permit good heat exchange. Therefore, parallelopiped and elongated-cylinder shapes are recommended. The higher ambient temperature shortens the retention time and at the same time reduces the digester volume needed. On the other hand, a long parallelopiped- or elongated-cylinder-shaped digester presents a long path for the digestion of the organic wastes.
- o Simplicity of operation requires a digester design with a fixed cover, fixed scum breakers, and self-stirring of the slurry.

- o Construction materials, such as ceramics, bricks, and cement should be availble in the country.
- o Low cost requires a reduced digester volume, thus waste loading and removal of an equal volume of digested solids are done daily. Biogas must be utilized twice a day.
- o The shallow digester model offers a large surface for the digester contents so that scum is thin and breakable. In some areas, especially in the Mekong delta, underground water may decrease the temperature of deep digesters.
- o The digester bottom should be inclined to concentrate digested solids into a place for removal.

2.2. Prototype

A prototype digester with oil drums has been made for research purposes. It consists of a closed drum as the main digester and a half drum as an equalization tank. Inside the main digester, two crossed and horizontal iron bars serve as scum breakers, helped by the up and down movement of the effluent caused by the inside pressure variation. This effluent movement also causes slurry self stirring.

This prototype serves as a model for the following digesters made of different construction materials.

2.3 Ceramic precast digesters

- o Small-scale digesters--As a partial solution to the health problem of disposing of animal wastes, a precast digester, made of ceramic, that is suitable for a small family has been designed. It consists of three pieces, each 80 cm in diameter, 30 cm high, and 2 cm thick, with cemented bottom, stacked vertically. This 300-liter main digester, with a 150-liter equalization tank, can take a daily loading from a

70-kg pig, with a 40-day retention time. The inlet is a pipe that extends inside the digester and the outlet is a valve at the bottom. The scum and stirring problems are resolved as described above.

- Household-scale digesters--The household-scale precast digester, also built of ceramic, is an assembly of many pieces forming a horizontal cylinder. Each unit between the inlet and outlet units is a short cylinder of 80 cm outside diameter, 40 cm long, with a 2-cm wall thickness, longitudinally separated into two parts: a main digester of 135 liters with two horizontal iron bars inside as scum breakers, and a 65-liter equalization tank. It can contain a daily loading from a 40- to 50-kg pig, with a 40-day retention time. The inlet and outlet pieces at the ends of the digester have the same diameter and wall thickness as the others, but are only 25 cm long. The surfaces of all these pieces are ceramic, and the cylinder bottom and longitudinal separators are cement. The number of digester units depends on the number of pigs being raised (up to ten pigs). The digested solids are removed from the bottom of the outlet by hand. Concrete units with a diameter of 4 cm are under consideration.

2.4 Brick and cement digesters

With brick and cement digesters, the hole between the main digester and the equalization tank is large enough to permit a man to get om for repair purposes. Scum breakers are made of iron bars like umbrella frames. Digested solids can be removed from the outlet by hand tools or hand pump. The size of a household digester is from 2.5 m^3 to 3 m^3, using the manure from eight 50-kg pigs. The ratio of digester volume to daily biogas production for all those digester varies from 1.8 to 2.5.

3. Batch Digestion - Jar Digesters

A prototype batch digester, made of a 60-liter glass flask and a used pneumatic chamber as gas holder, serves as a model for household-size units. This type of digester consists of seven 200-liter ceramic water jars and a 700-liter plastic or rubber gas holder. Loading is accomplished with a funnel through a 10-cm diameter hole located in the cover of each jar and closed by a rubber plug. Gas is released from the jar through a valve on the cover, and is conducted to the holder by a plastic pipe. A 10-cm wide outlet on the side, next to the bottom, is also closed with a rubber plug. Each jar in turn is opened to remove digested manure, and to be loaded with fresh dung and water over a period of seven days. It is then closed to start the digestion. The retention time is then six weeks, and the biogas production is about 1,200 liters per day. The daily loading from four to five 50-kg pigs needs four 200-liter water jars with a 400-liter plastic or rubber gas holder. The six-week retention time does not include the two weeks required for loading. (The gas holder can be 20 pneumatic chambers.)

APPENDIX B

SYMBOLS

B	Loading rate
BOD_5	Five-day biological oxygen demand
$^{\circ}C$	Degrees Celsius (Centigrade temperature)
cm	Centimeter
cm^2	Square centimeter
COD	Chemical oxygen demand
C_p	Heat capacity at constant pressure
d	Day
e (subscript)	Effluent
g	Gram
h	Hour
hp	Horsepower
HPLC	High-pressure liquid chromatography
I-C	Internal-combustion
J	Joule
kW	Kilowatt
kWh	Kilowatt-hour
l	Liter
m	Meter
m^2	Square meter
m^3	Cubic meter
mm	Millimeter
o (subscript)	Influent
P	Power
PVC	Poly-vinylchloride
Q	Heat
r	Production rate (gas or methane)
s	Second
S	Substrate
T	Change in Temperature
t	Time (hours)
TS	Total Solids
TSS	Total suspended solids
V	Volume
VS	Volatile solids
VSS	Volatile suspended solids
w	Weight
X	Concentration of active mass of microorganisms
Y	Yield or conversion ratio

APPENDIX C - GLOSSARY

ANAEROBIC BACTERIA: Bacteria that grow only in the absence of free elemental oxygen.

ANAEROBIC CONTACT PROCESS: An anaerobic digestion process in which the microorganisms are separated from the effluent slurry by sedimentation or other means and held in or returned to the digester to increase the rate of stabilization.

ANAEROBIC DIGESTER: A unit operation or a reactor that is constructed to bring about the degradation and stabilization of organic matter by anaerobic bacteria.

ANAEROBIC DIGESTION: The degredation and stabilization of organic materials brought about by the action of anaerobic bacteria.

BENEFITS:

TANGIBLE: The advantages or benefits of a biogas system that are easily quantifiable and have a monetary value. Such benefits include the value of the gas and the fertilizer produced.

INTANGIBLE: The advantages or benefits of a biogas system that are not so easily quantified or related to a monetary value. Examples include the value of comfort and leisure gained and value due to an improvement in the general asthetics, health and sanitation.

BIOGAS: The gas that is produced by subjecting waste organic materials to anaerobic digestion. This gas contains primarily methane and carbon dioxide.

BIOMETHANATION: A biochemical process in which methane is produced from waste organic materials by the action of specific groups of anaerobic bacteria.

CALORIFIC VALUE: The amount of heat that can be obtained from a fuel and is usually expressed in terms of calories per unit weight of the fuel.

COMMINUTION: The process of cutting and shredding to reduce the particle size of materials, such as feedstocks before they are introduced into a digester.

COMPOSTING: Waste stabilization process that is carried out under aerobic conditions principally by thermophilic microorganisms.

DEWATERING: The process of removing water from the slurry (effluent) exiting from a digester.

DIGESTER:

SMALL-SCALE: These are generally less than 10 m^3 and are meant to stabilize small volumes of waste organic material.

SINGLE-FAMILY: A small-scale digester designed to digest the waste materials generated from a single household, including the wastes of the livestock it owns.

Community: These digesters are considerably larger in size than the single-family digester and process the wastes generated by a community. The community may comprise the entire human and cattle population of a village or only a part of it.

Institutional: A fairly large-size digester that receives and digests the wastes of an institution such as a dormitory, jail, hospital, hotel, etc.

Industrial: These digesters may be of comparable sizes to those of community or institutional digesters and receives wastes exclusively from a specific industry such as a dairy, animal-feed factory, feed lot, slaughter house, or poultry farm.

Batch: These types of digesters receive one charge of waste materials, such as agricultural residues, and yield biogas over a period of time without daily or intermittent feeding. When the waste is stabilized, the digester is emptied and then filled with a fresh charge of raw waste material and the process is continued.

<u>Semi-Continuous With Recycle of Slurry</u>: In this type of digester, the feed materials are introduced into the system intermittently depending on their availability. A part of the effluent slurry is recycled to the digester daily to provide active microorganisms for the degradation of the incoming substrate.

<u>Semi-Continuous Without Recycle of Slurry</u>: Same as above except effluent slurry is not recycled into the digester.

<u>Continuous With Recycle of Slurry</u>: In this type of digester the substrate is fed into the digester on a contiuous basis accompanied by the recycle of a part or all of the solids in the effluent slurry.

<u>Water pressure</u>: In this type of digester, the pressure exerted by the gas may vary by as much as 1000 mm of water due to the fixed dome nature of the digester - hence its name.

DIGESTER: A reactor or unit operation into which waste organic materials are introduced for their stabilization and production of biogas.

ENRICHING: A process by which the fertilizer value of wastes is enhanced either by digesting them or by supplementing the digested slurry with additional nutrients such as compounds containing nitrogen, phosphorus, and potassium.

GAS HOLDER: An appurtenance that holds the gas produced in a digester.

HEAT CAPACITY: The amount of heat required to increase the temperature of a body by one degree.

HYDRAULIC RETENTION TIME: The average time that a liquid stays in a reactor before it is discharged. It is equal to the volume of the reactor divided by the flow rate of the liquid entering it. It is usually expressed in days but may be as short as hours.

INACTIVATION: The process by which parasite eggs, pathogenic bacteria, viruses, and vegetable seeds are rendered inactive and hence unable to propogate.

INOCULUM: Any material, such as previously digested manure, that is added to a newly started digester to hasten the degradation of organic matter and the production of methane.

LAND CARRYING CAPACITY: The capacity of a given area of land to sustain human and animal life on a continuing basis.

MARKET PRICE: The prevailing price of a commodity in a competetive open market.

PHOTOVOLTAICS: Devices used to convert solar energy directly into electricity.

PROCESS HEAT: The heat that is used in operating and maintaining a production activity in the manufacturing and/or processing of goods and materials.

PRODUCTION RATE: The volume of biogas produced per day per unit volume of the digester capacity. (The percentage of methane in the biogas produced should be indicated for meaningful use of such data.)

RATE OF RETURN (%): The ratio of net profit obtained to the investment made.

SOLIDS RETENTION TIME: The average residence time that a solid particle stays in a system before it leaves. It is calculated by dividing the mass of solids in a system by the mass of solids removed per day from the system. It is usually expressed in days.

SHAFT POWER: Mechanical power provided by rotating machinery.

SPACE HEATING: The heating of dwellings on other buildings.

SPECIFIC HEAT: The heat capacity of a unit mass of material.

THERMAL CONDUCTIVITY: The quantity of heat that flows in one second between opposite faces of unit cube of a material, under a temperature difference of one degree between those faces.

TOTAL AVAILABLE CARBON: The amount of carbon available in a substrate that can be used by living organisms for cell synthesis. Such carbon represents a measure of the biodegradable carbonaceous materials.

YIELD: The volume of biogas produced per unit weight of substrate (or its chemical oxygen demand) added to the system. The retention time of the system should be specified for meaningful use of the data. Also the yield can be expressed as the volume of biogas produced per unit weight of volatile solids destroyed, or as chemical oxygen demand satisfied.